

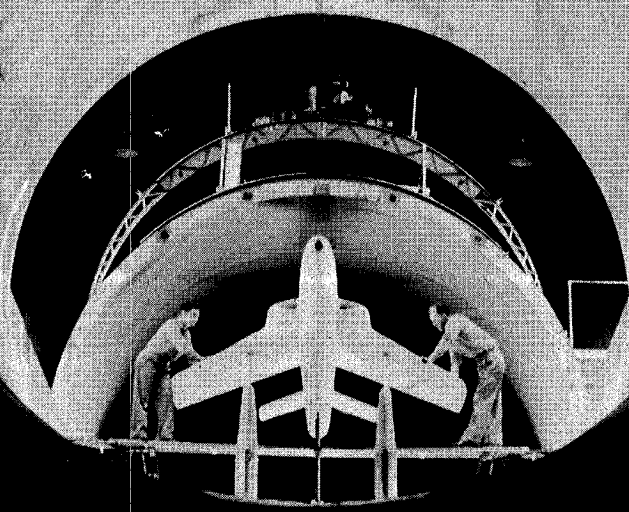
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THE NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS



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THE AIRCRAFT OF TOMORROW

In the span of half a century, man has mastered the secrets of flight and has learned to build airplanes that fly faster than the speed of sound. Since the first powered flight at Kitty Hawk on December 17, 1903, the rapid progress of aircraft design has been one of the wonders of modern science and engineering.

This progress did not come easily. Aeronautical principles that are now common knowledge to the high school boy were baffling to the early scientists and designers.

Today's aircraft are based on intensive research by individual scientists, teams of researchers, and entire large laboratories. As knowledge and understanding have increased, new problems have arisen and whole new fields have been opened.

Meanwhile, at any given time, the aircraft industry's design engineers are limited by the existing range of dependable research knowledge.

In the early days, the problems of flight were in subsonics. Today they are also in transonics, supersonics, hypersonics, thermodynamics.

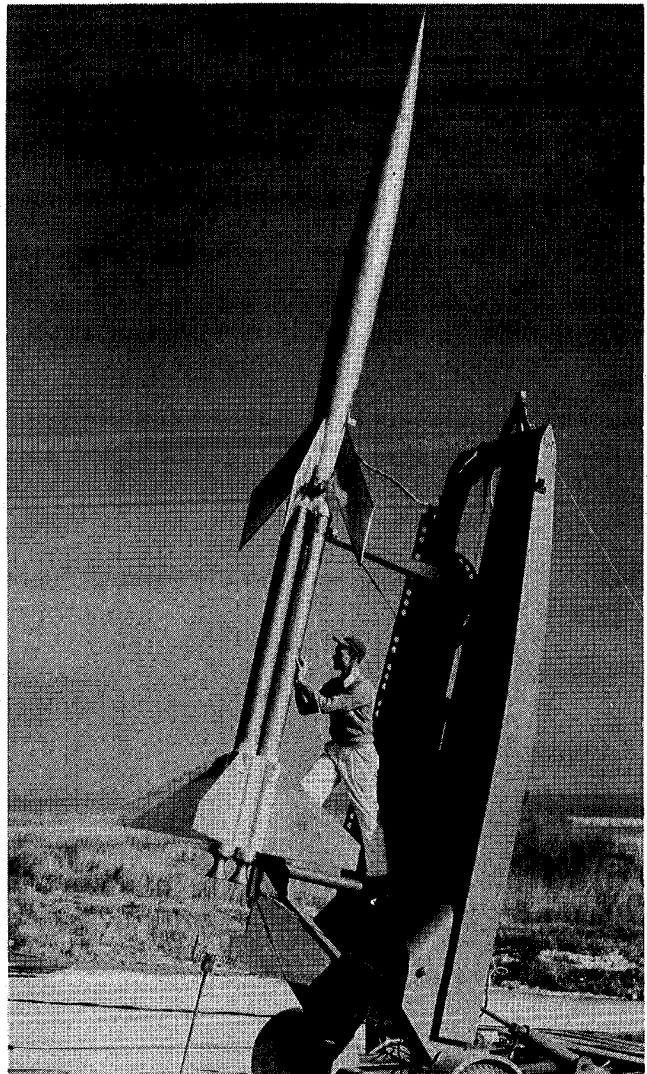
For many years, flying machines were ungainly biplanes and triplanes. Today they are sleek thin-winged monoplanes, with revolutionary new shapes here and in prospect.

At first, aircraft structures and materials involved problems of wood, wire, and fabric. Today they are mostly problems of metals, plastics, ceramics, glass. Tomorrow's problems will involve man-made materials as yet uninvented.

Formerly, the propulsion of aircraft involved reciprocating gasoline engines; today, jets and rockets; tomorrow - who knows?

The challenge of aeronautical research today is strong, the problems are many and complicated, the unanswered and even unasked questions are intriguing.

The nation's major organization for basic aeronautical research, since 1915, has been and is the National Advisory Committee for Aeronautics.



RESEARCH MISSILE WITH BOOSTER ROCKET



EXPERIMENTAL WING-BODY COMBINATION AT AMES, IN CALIFORNIA

THE NACA

The Nation's Aeronautical Research Establishment

The business of the National Advisory Committee for Aeronautics is research - scientific laboratory research in aeronautics.

Known to everyone in the aircraft and aviation industries as the NACA, this independent agency of the Federal Government was established by Congress in 1915 with instructions to "supervise and direct the scientific study of the problems of flight, with a view to their practical solution," and to "direct and conduct research and experiment in aeronautics."

This the NACA does on a much bigger scale than was contemplated in 1915, when aviation was in its infancy. NACA has steadily grown into the world's greatest aeronautical research establishment - large, diversified, and geographically dispersed.

The NACA now operates three large research centers located in Virginia, Ohio, and California, and two field stations in Virginia and California. The United States Government has invested more than \$200 million in the NACA's laboratories, buildings, and equipment.

The NACA staff now consists of about 7,500 men and women, all Civil Service employees. Nearly one third of them are professional scientists and engineers, more than one third are skilled trades and crafts workers of many different types, and the rest are technicians and other supporting personnel.

AREAS OF RESEARCH. The research programs may be divided into four broad categories: (1) Aerodynamics, the study of air flow over and around the airplane and through its propulsion system; (2) Aircraft Power Plants, covering all types of engines and fuels; (3) Aircraft Construction, which includes the airframe structure, materials used, and loads imposed upon them in flight and in landing, and (4) Operating Problems such as meteorology, icing, fire prevention, and ditching.

Military, commercial, and private aviation benefit from NACA's work. The research programs have both the long-range, all-inclusive objective of acquiring the new scientific knowledge essential to assure American leadership in aeronautics, and the immediate objective of solving, as quickly as possible, the most pressing problems, thus to assure success of the nation's aircraft construction program.

Although NACA scientists sometimes attack an immediate problem - for example, lack of stability in a new fighter plane - they devote most of their time to fundamental research in advanced border areas several

years ahead of current models. In their daily work, they continually push forward the frontiers of aeronautical knowledge.

The fundamental research is not aimed at improving any particular airplane, but rather at obtaining a basic understanding of the physical phenomena involved in problems affecting all types of aircraft. In the course of their investigations, the scientists compile generalized design data for aircraft of all types - bombers, transports, fighters, helicopters, seaplanes, and personal airplanes.

NACA HEADQUARTERS. In Washington, D. C., is located the NACA Headquarters, nerve center of the far-flung research activity of the National Advisory Committee for Aeronautics. Relatively small in staff, it coordinates and controls research and administration, and maintains liaison with the military services, other Government departments and agencies, universities and other research organizations, and the aircraft industry.



NACA HEADQUARTERS, WASHINGTON, D. C.

LANGLEY: AERODYNAMICS, STRUCTURES, LOADS, HYDRODYNAMICS. The Langley Aeronautical Laboratory at Langley Field, Virginia, is the NACA's oldest, largest, and most diversified research center. It is located near Hampton, across Hampton Roads from Norfolk.

Langley first started operations with two open-cockpit biplanes loaned by the Army, two hangars, and a few engineers, pilots, and mechanics. Its first permanent building was erected in 1918 and its first wind tunnel was built in 1919.

Until 1940, all NACA research was conducted at Langley, which still has 40 percent of the total staff. It now has 20 wind tunnels of many types - subsonic, transonic, supersonic, and specialty - and other extensive research facilities.

Research at Langley includes all aspects of aerodynamics, including many specialized fields such as stability and control, flutter and vibration, aerodynamic loads, and rotary wing aircraft.

The work in aircraft structures and landing loads is centered at Langley, and also the research in hydrodynamics.

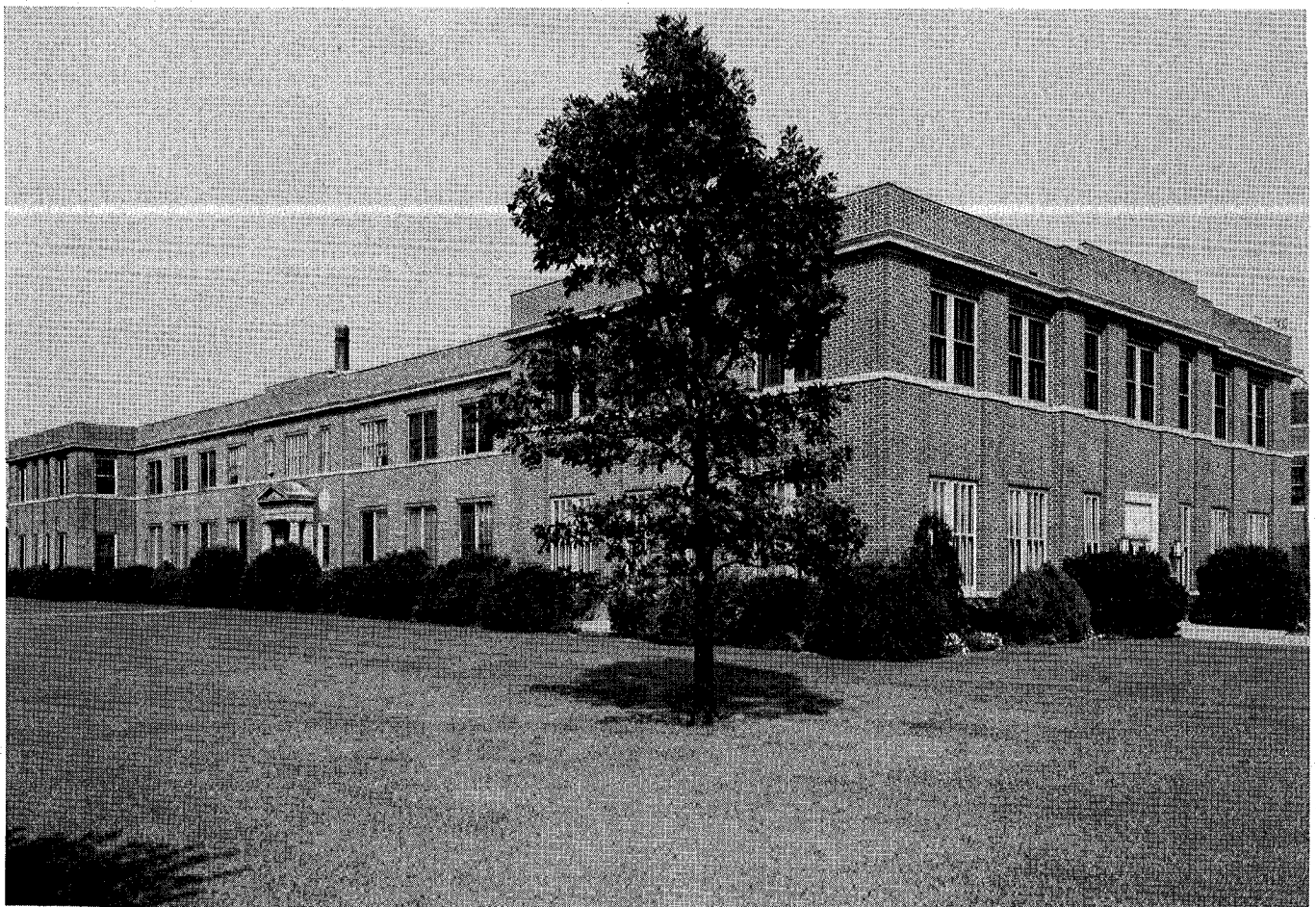
AMES: HIGH-SPEED AERODYNAMICS. The Ames Aeronautical Laboratory, Moffett Field, California, 38 miles south of San Francisco, was constructed in 1940 to concentrate on problems of high-speed aerodynamics.

Some of the world's largest and fastest supersonic wind tunnels are located at Ames. Among its subsonic facilities is the world's largest wind tunnel, capable of testing a full-size airplane with a 70-foot wing span at speeds up to 250 mph.

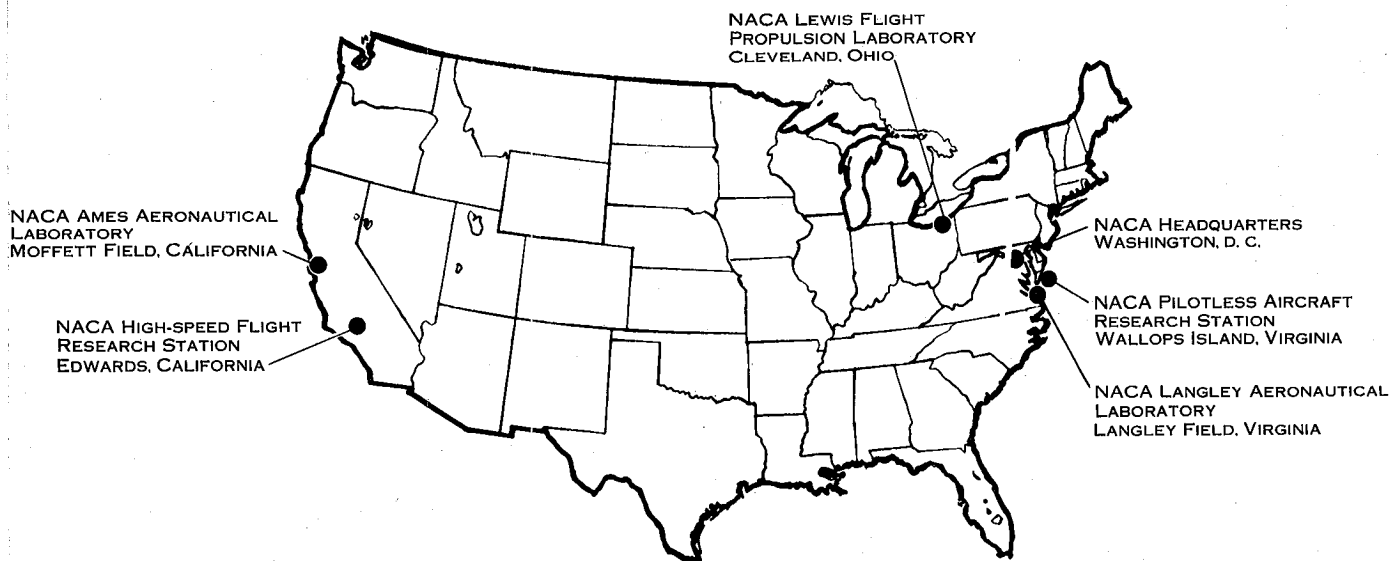
LEWIS: FLIGHT PROPULSION. In 1942, adjacent to the municipal airport at Cleveland, Ohio, was constructed the Lewis Flight Propulsion Laboratory.

Here, utilizing the most modern of research tools, the problems of propulsion can be studied through the full range from the chemistry of fuels to the operation of full-size engines under simulated conditions of high-altitude flight.

Among the many problems investigated are combustion, fuels, cascade aerodynamics, propulsion-system structures, high-temperature materials, and lubrication.



ADMINISTRATION BUILDING AT NACA'S LANGLEY LABORATORY, IN VIRGINIA



All types of modern and future systems of aircraft propulsion are studied, including turbojets, turboprops, ram jets, rockets, and others.

EDWARDS: PILOTED FLIGHT RESEARCH. In the Mojave Desert northeast of Los Angeles is the NACA High-Speed Flight Research Station, Edwards, California.

Here, specially-designed research aircraft are flown by skilled research pilots at transonic and supersonic speeds. History was made at Edwards with the first successful piloted supersonic flight in the X-1. Aeronautical history is still being made there, much of it unpublishable as yet.

WALLOPS: PILOTLESS AIRCRAFT RESEARCH. The NACA Pilotless Aircraft Research Station is located on Wallops Island, Virginia, not far from Langley.

From launching stands, rocket-powered missiles and research models are fired out to sea. By means of radar tracking, telemetering, and other techniques, data are obtained on stability and control and other flight characteristics in the transonic and supersonic ranges.

CONTRACT RESEARCH. Some NACA research is done elsewhere than in its own laboratories and field stations.

For example, NACA takes advantage of the research talents and facilities of universities and other nonprofit scientific institutions by awarding contracts for the investigation of specific problems. This has the further advantage of introducing graduate and undergraduate students to the challenging and exacting requirements of professional research, giving them an opportunity to develop their capabilities and to acquire

a taste for aeronautical work. A number of engineering schools have wind tunnels and other facilities for such research.

In addition, some NACA research is performed on a contract basis in other laboratories owned by the Federal Government. Examples are the National Bureau of Standards and the Forest Products Laboratory, which have special facilities for certain types of investigation.

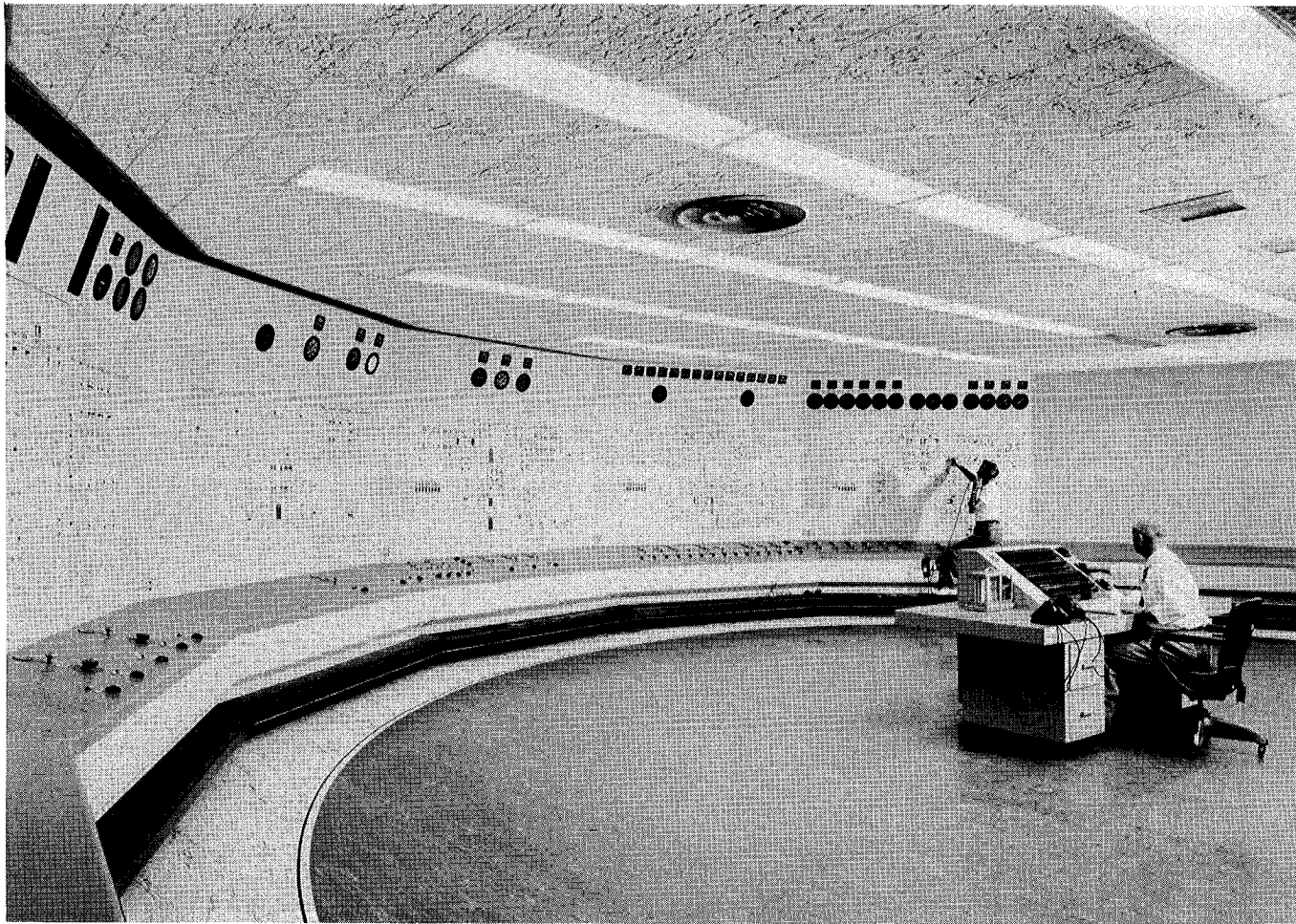
COORDINATION OF RESEARCH IN AERONAUTICS: ANOTHER FUNCTION OF NACA. In addition to doing and contracting research, NACA has the responsibility of coordinating research work in aeronautics.

This function is reflected in the title "National Advisory Committee for Aeronautics," and also in the basic legislative directive of 1915 to "supervise and direct the scientific study of the problems of flight."

To carry out this function, the NACA is headed by a Main Committee of 17 members appointed by the President of the United States. This committee includes top-rank representatives from the Air Force, Navy Bureau of Aeronautics, Research and Development Board, Civil Aeronautics Authority, National Bureau of Standards, Smithsonian Institution, executives of the aircraft industry and commercial airlines, and prominent scientists.

Twenty-eight technical committees and subcommittees assist the Main Committee in deciding what research programs to undertake. The major committees are composed of specialists in either Aerodynamics, Power Plants for Aircraft, Aircraft Construction, or Operating Problems. Each committee is supported by several technical subcommittees.

A fifth major committee, called the Industry Consulting Committee, assists the Main Committee.



AIR IS SUPPLIED TO 100 RESEARCH FACILITIES FROM CONTROL ROOM AT LEWIS, IN OHIO

The technical committees and subcommittees include over 400 scientists and engineers connected with universities, aircraft companies, commercial airlines, the military services, civilian agencies, and the NACA. These men are selected because of their technical ability, experience, and recognized leadership in a special field of competence. They, like the members of the Main Committee, serve without compensation.

These many committees and subcommittees review aeronautical and related research being carried on by the NACA and other agencies, recommend problems that should be investigated, and assist in formulating a coordinating program for research by the NACA and other organizations. They are an invaluable medium for the interchange of information regarding investigations and developments in progress or proposed.

RESEARCH vs DESIGN AND DEVELOPMENT. The principal duty of the NACA is to do basic and applied research on the fundamental problems of aeronautical science. This research produces detailed scientific and technical information for use by design and development engineers.

All existing airplanes, whether military, commercial, or private, embody principles and design features

discovered or refined in NACA laboratories. Even the NACA's pioneer work in drag reduction, engine cooling, and choosing the best shapes for wings, propellers, and air ducts still guides aircraft designers today.

The NACA's chief mission is to keep ahead of the aeronautical procession by continually discovering and refining new knowledge. This new knowledge is essential for the design of new airplanes, new power plants, and new missiles, all of superior performance, for tomorrow as well as for today.

When war threatens or actually occurs, NACA is faced with an additional responsibility. Much of the fundamental research must be sidetracked so that NACA research equipment and brains may be used on urgent projects requested by the armed forces. It may be that technical information is needed by designers for a new military plane still in the development stage. Or it may be that a "quick fix" of an existing type is needed, to cure defects such as excessive drag, engine overheating, or insufficient control and stability. For example, early in the last World War many military planes picked up an additional 10 to 20 mph during "drag clean-up" tests in the Full-Scale Wind Tunnel at Langley, and fatal spinning characteristics were cured after diagnosis in the Spin Tunnel.

Even when pressed by emergency design and development problems, NACA still holds to its prime aim of searching out new research information for the aircraft of the future.

REPORTS: NACA'S END PRODUCT. The results of NACA's vast and varied research are published in four forms: Technical Reports, Technical Notes, Technical Memorandums, and Research Memorandums. All of these are made available to the aircraft industry, commercial operators, and the military, according to their needs and within security limits.

Some 800 or 900 NACA publications are issued every year, many of them classified "restricted," "confidential," or "secret." Distribution of the classified subjects is closely controlled. At any one time, hundreds of scientific investigations are under way at the three laboratories and two research stations to provide information for these publications.

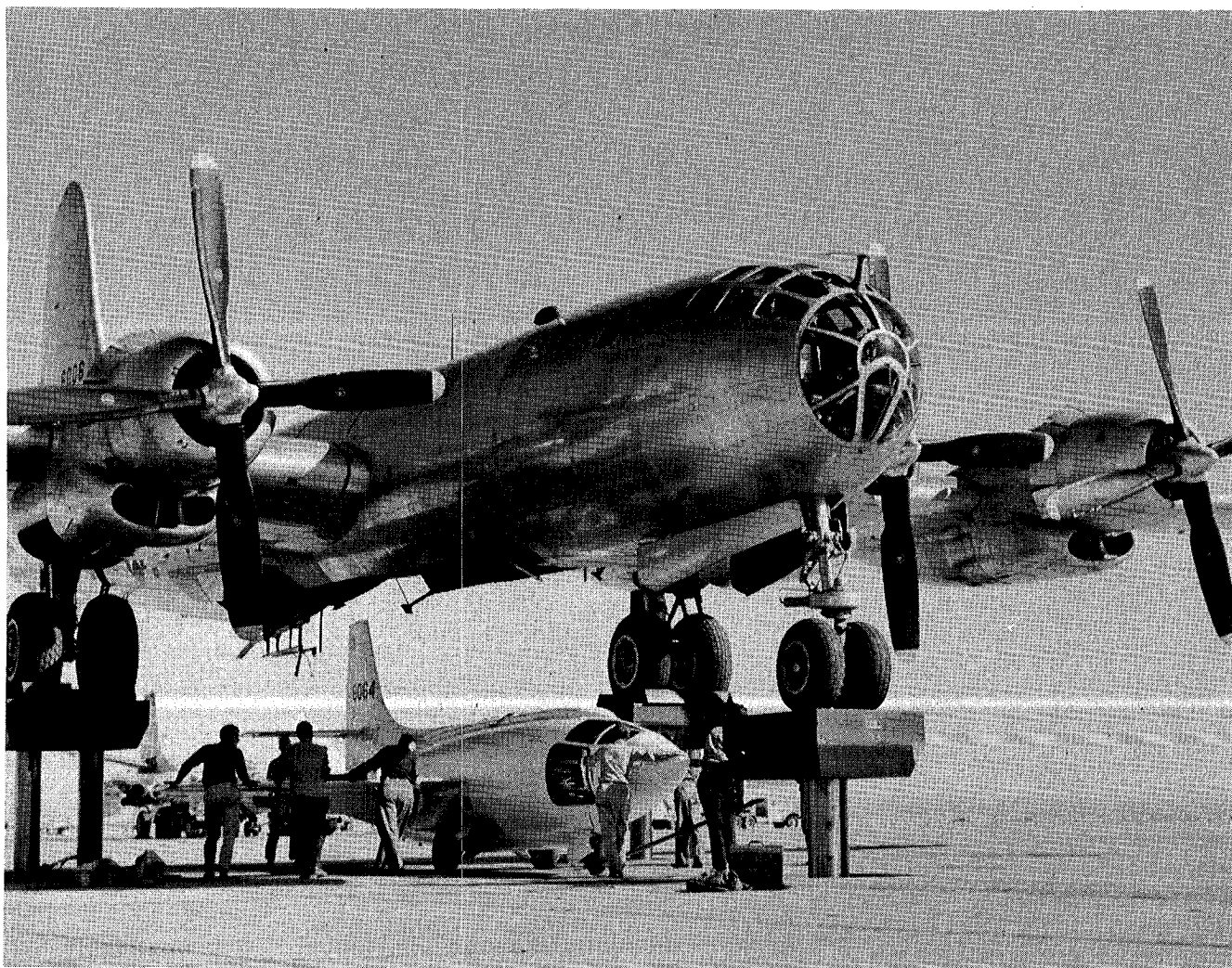
Reports of its scientific findings are also made by NACA through conferences held for representatives of

the aviation industry, the military services, or engineering colleges. Each such conference usually covers one current phase of research in some detail.

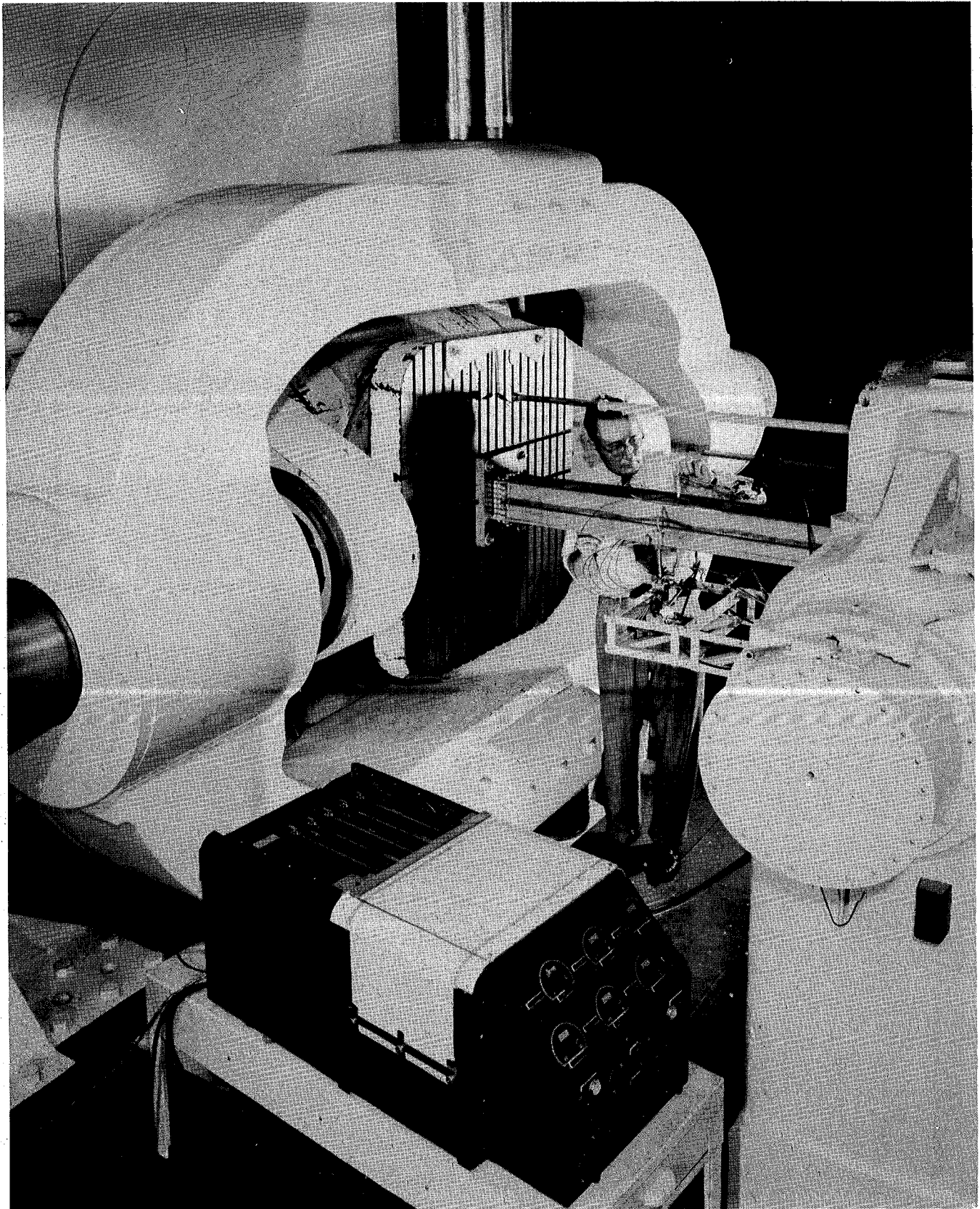
Every year one of the NACA research centers holds a full-dress inspection of its facilities to present its current research problems and findings, within security limits. To these inspections are invited several hundred aircraft executives, engineers, military officers, educators, and Government officials.

NACA also serves as a clearinghouse for aeronautical information. The Office of Aeronautical Intelligence in Washington is a large library of scientific and technical information, maintained at NACA Headquarters for the collection, classification, compilation, and dissemination of aeronautical knowledge.

Thus through publications, conferences, inspections, library, films, technical lectures and papers, and also a constant stream of correspondence and personal visits, the NACA disseminates its research and technical information, thereby contributing toward increases in aircraft speed, range, payload, maneuverability, economy, and safety.



PREPARING X-1 RESEARCH AIRPLANE TO BE CARRIED ALOFT BENEATH BOMBER, EDWARDS, CALIF.



STRUCTURES SCIENTIST EXAMINES SPECIMEN IN COMBINED LOADS TESTING MACHINE.

TOOLS OF AERONAUTICAL RESEARCH

The NACA has unexcelled facilities for aeronautical research. Among them, for example, are America's largest wind tunnels, the first transonic tunnels, and some of the largest and fastest supersonic tunnels. NACA also has the most modern facilities capable of operating today's largest jet engines under simulated flight conditions at high altitudes. One tunnel produces freezing rain and wind for the study of icing conditions. Others are specialty tunnels to study spinning, free flight, gusts, stability. Some have test sections only a few inches in diameter, some are "blow-down" tunnels, some have variable air density. There are dozens in all, each with special research usefulness.

In addition, NACA has seaplane towing tanks for hydrodynamic studies, an impact basin for measuring landing loads, a helicopter tower, and launching and tracking devices for missiles.

Structures research is provided for by equipment that is both massive and delicate. An example is the combined loads testing machine shown on the opposite page, which can impose loads and measure results in many directions simultaneously.

For propulsion research, the five and one-half acre Engine Research Building has a wide variety of equipment for studies of compressors, turbines, combustion chambers, and other engine components. Other facilities are used for high-temperature materials, lubrication, and engine fuels, with separate laboratories for high-energy fuels and rocket engine performance.

In addition to these and many other experimental facilities, flight research utilizes full-scale airplanes for the exploration of aeronautical problems which can be investigated adequately in no other way.

Research instrumentation has an important place in the picture, since the most carefully performed experiment is virtually worthless without precise measurement and recording of data.

Mathematical and statistical analysis is also vitally important, since a single experiment may produce long series of interrelated measurements which must be disentangled analytically. Here the new mechanical and electronic "brains" help by analyzing speedily huge masses of data.

In using all these and other research tools, mathematical theory provides both guidance and goals. Hypotheses provide ideas for and give guidance to experimentation. As experimental data prove, disprove, or modify these hypotheses, principles and laws emerge

expressed in mathematical formulas. Such proven aeronautical theory is the goal of research, for it becomes the basic tool for the prediction and control of aeronautical phenomena used by aircraft design engineers in planning planes and missiles of the present and future.

Although the tools and techniques of research are varied and powerful, trained minds and driving interest are essential in applying them to aeronautical research problems. The following statement by Dr. Hugh L. Dryden, director of the NACA, underlines this truth:

"The most important tools in aeronautical research, even more important than our two-hundred-million-dollar research plant, are the brains of the scientists, engineers, and supporting personnel of the NACA staff. The individual worker is the most essential element in NACA accomplishments."



RESEARCH PILOT CONFERS WITH CREW CHIEF

SUBSONIC AERODYNAMICS

Subsonic aerodynamics is the broad field covering the study of air flow around the wings and other surfaces of aircraft flying at speeds up to about Mach .70, which is 70 percent of the speed of sound or about 532 mph at sea level. At about this speed, compressibility effects begin to be felt at low altitude, as the transonic range is entered.

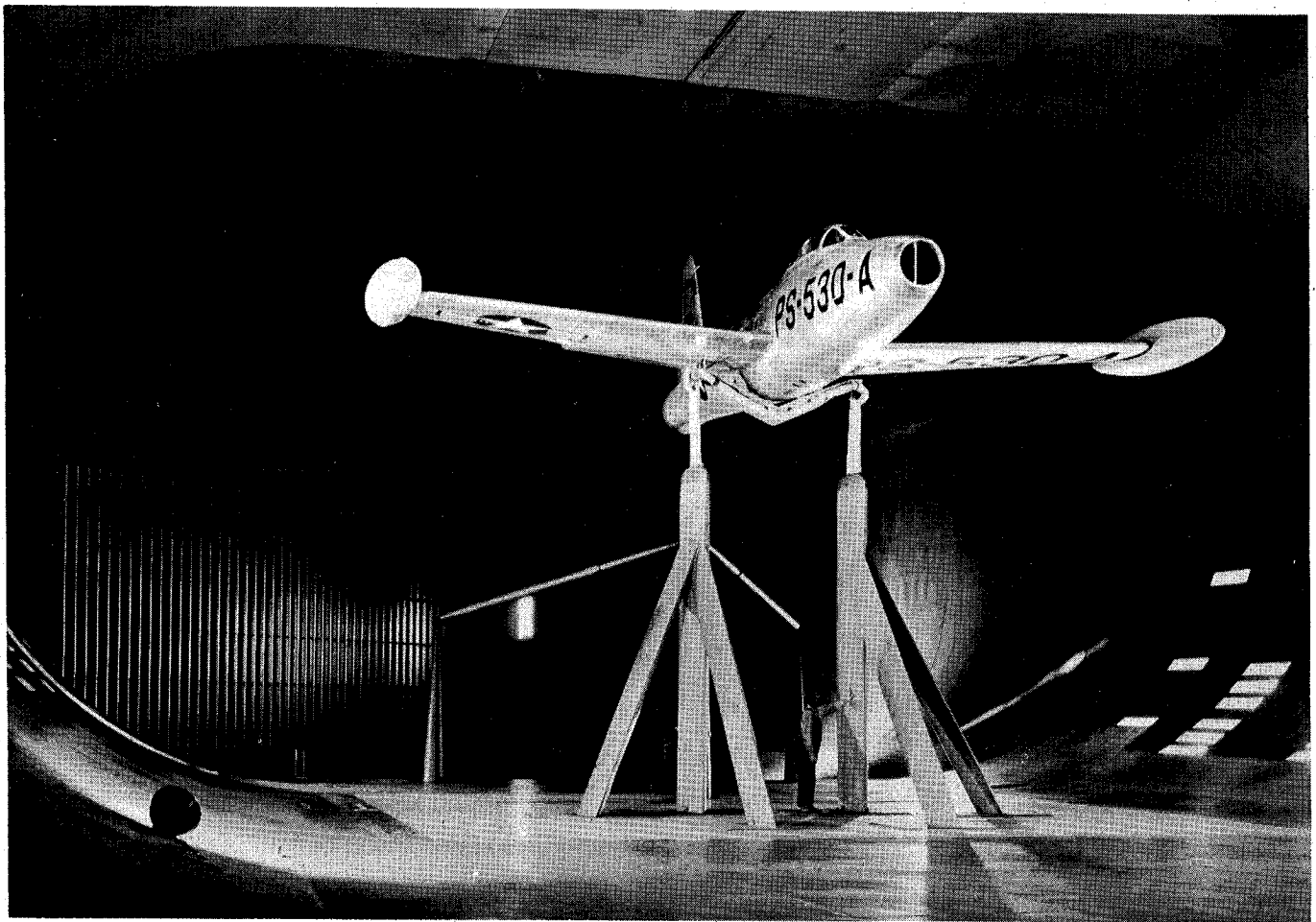
The upper boundary of the subsonic range is not definite, however, and may extend to considerably higher speeds at higher altitudes or with swept-wing configurations. The speed band between Mach .70 and .90 is where subsonic theory dies out in the face of increasing transonic flow.

Subsonic aerodynamics involves the investigation of a great variety of airfoils and aerodynamic shapes. Detailed studies of drag at key points on the airplane constitute a large part of the work. Subsonic research also includes extensive study of the details of air flow over the aircraft, particularly in the boundary layer very close to the surface, and analysis of the mutual interference effects of airplane components in combination.

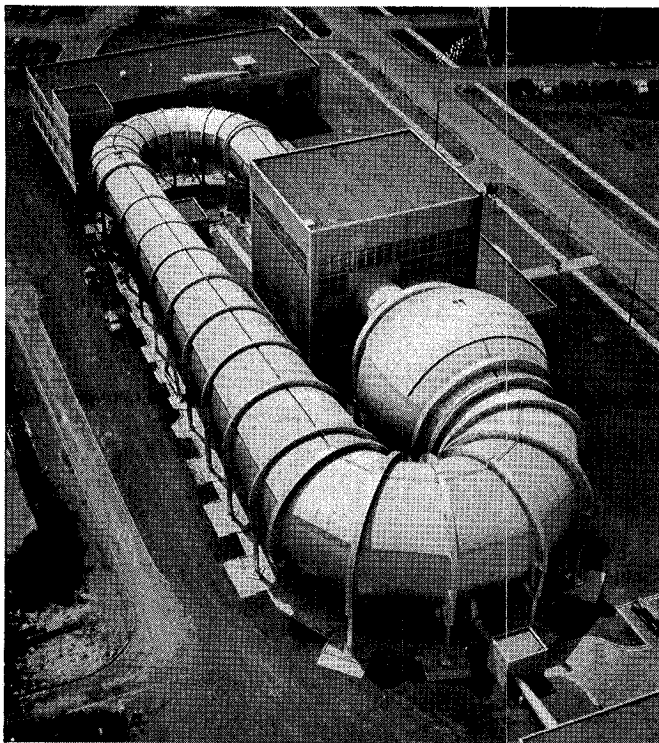
In a systematic program, the work usually involves development of theory, progresses to experimental verification and development in specialized wind tunnels, and is then extended to larger scale in full-scale wind tunnels and pressure tunnels.

In presenting aerodynamic research methods, it should be stated that flight research, the first method employed, is still one of the most important. Tests conducted in actual flight yield the best results in many types of investigations, and are especially valuable in high-speed studies of complete airplane configurations. The NACA makes wide use of flight research.

One particular advantage of flight technique is the fact that the airplane itself acts as an automatic integrator to include all factors affecting the flight characteristics of an airplane, whereas in wind tunnel studies strong efforts are made to eliminate all but singular factors. In some cases, the non-aerodynamic factors play an important part in determining the flight characteristics of the airplane. Their evaluation, in conjunction with the aerodynamic factors, is necessary for the proper design compromises and for evaluation of the whole airplane.



F-84 THUNDERJET MOUNTED IN 40 x 80-FOOT FULL-SCALE TUNNEL AT AMES



LOW-TURBULENCE PRESSURE TUNNEL AT AMES

Many subsonic investigations are conducted in wind tunnels, and most of NACA's older tunnels were designed for this speed range. The majority of the subsonic work is handled at Langley Laboratory, but Ames Laboratory has the world's largest full-scale wind tunnel, with a test section 40 x 80 feet and air speeds up to 250 mph.

Wind tunnels have been designed for a variety of purposes since NACA's first "atmospheric wind tunnel" was built in 1919. The NACA pioneered the design and use of full-scale wind tunnels and pressure tunnels, among others.

The full-scale tunnels at Ames and Langley are large enough to test a real, full-size fighter plane or any single-engine airplane. The Ames tunnel can handle twin-engine planes, too. Tests can be carried on while engines and propellers are operating.

Both full-scale tunnels are used for large-scale drag investigations and boundary-layer control studies. They have proved particularly valuable for investigating stability and control, in the landing speed range, of large-scale wings and aircraft shapes designed for high-speed and supersonic flight.

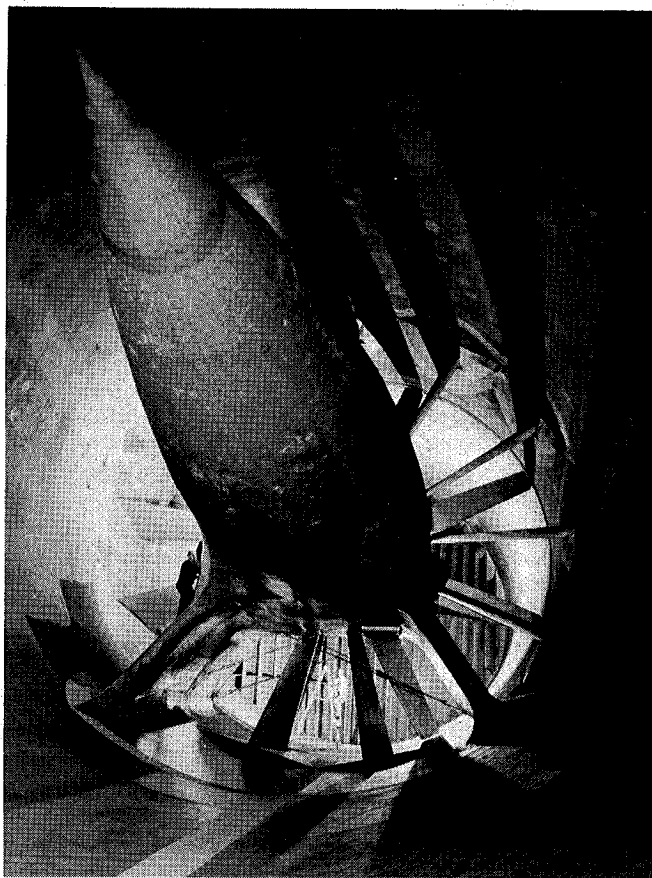
Although the Langley tunnel's top speed is only 110 mph, it continues to be a valuable research tool in the study of high-speed wings under conditions simulating landing and takeoff. The tunnel is also used in research on unconventional wings of low aspect ratio, and on helicopters.

This shift in emphasis from evaluation of the whole airplane at cruising speeds to the landing speed problems of the new, faster planes applies to all wind tunnels in the low-speed range.

One aim in aerodynamic research is to obtain test results that are as near full-scale as possible. If the size of the model cannot be increased, the same result may be obtained by increasing the density of the air flowing past the model. A pressure of three atmospheres, for example, gives the same effect as a model three times as large. Thus the use of compressed air in a wind tunnel increases the Reynolds number to approach that of the complete aircraft, as was demonstrated by the NACA's first variable-density tunnel in 1923.

Operating on this principle, the 19-Foot Pressure Tunnel at Langley and the 12-Foot Low-Turbulence Pressure Tunnel at Ames are used to extend research on airfoils to the study of complete wings at high Reynolds numbers. They are well adapted for study and improvement of complete wing characteristics, the development of high-lift and lateral-control devices, and evaluation of improvement of stability, control, and performance characteristics of airplanes in the design stage.

In a pressure tunnel, the scientist has at his command a special device to study the effects of model scale, or size, on air flow behavior, independently of the effects of speed. By varying the air density while holding constant speed, and by varying the speed while maintaining the same density, the scale effects can be isolated and defined.



WIND TUNNEL MOTOR AND FAN

TRANSONIC AERODYNAMICS

Tremendous strides have been made in the study of transonic aerodynamics during the past few years. Research airplanes, pilotless aircraft, and wind tunnels are all probing the secrets of this intermediate speed regime, the last to yield to scientific exploration.

NACA's latest achievement in transonic research is the design and development of transonic wind tunnels, which had been considered "impossible" to build. For this feat, John Stack and his associates at Langley Laboratory were awarded the Collier Trophy for 1951. Stack also won a share in the 1948 trophy for his work on the X-1 research airplane.

The importance of transonic research lies in the fact that any supersonic airplane will have to be able to fly safely through the transonic speed zone, without excessive drag and loss of control. The plane must have good flying characteristics in three speed ranges which present conflicting demands upon the designer: subsonic, transonic, and supersonic.

The transonic speed range is defined by the co-existence of mixed subsonic and supersonic flows; it does not have exact boundaries, and it varies with configuration. Generally, it may be said to extend from about 0.7 to 1.3 times the speed of sound, which corresponds to airplane speeds between 530 and 990 mph under standard sea level conditions. In the cold upper atmosphere above 35,000 feet, where the speed of sound is only 661 mph, transonic effects may be encountered at 460 mph and continue to be felt until about 860 mph. Some of the newest fighter planes are able to penetrate deeply into the transonic region, and even into the low supersonic region, which overlaps the transonic.

The two principal problems in transonic research are (1) reduction of drag and (2) improvement of stability and control. High transonic drag can prevent an airplane from attaining its necessary tactical requirements, besides wasting fuel. Efforts are centered on

reducing the peak levels of transonic drag. The loss of control is caused by a sudden rise in drag and deterioration in lift which occur as the airplane enters the transonic zone. To some extent, both the drag and control problems can be minimized by radical wing design.

Unfortunately, it is not possible to design an ideal wing shape that would be efficient in all three speed ranges. The wing must be a compromise, probably of sweptback or triangular design.

NACA research in wind tunnels, the structures laboratory, and other facilities contributed importantly to the successful design of the first airplanes to achieve level flight faster than the speed of sound, the Bell X-1 and the Douglas D-558-II Skyrocket. These and half a dozen other research airplanes, in turn, are now producing a mass of detailed full-scale data that will prove invaluable in designing tactical military aircraft.

Long before the X-1 proved supersonic flight was possible in 1947, NACA scientists had been trying to design wind tunnels suitable for transonic flow studies. It was a well known fact, and a severe handicap to aeronautical research, that wind tunnels were unable to obtain reliable data very close to the speed of sound, between Mach 0.9 and 1.2. At these critical speeds, extraneous shock waves formed in the test section, making accurate measurements impossible.

This blind spot in aeronautical research was eliminated early in 1951 when NACA announced the successful development of large wind tunnels capable of yielding accurate data throughout the whole transonic speed range. After several years' study, the scientists had found a way to eliminate the "choking" effect by designing a new test section for the transonic wind tunnel.

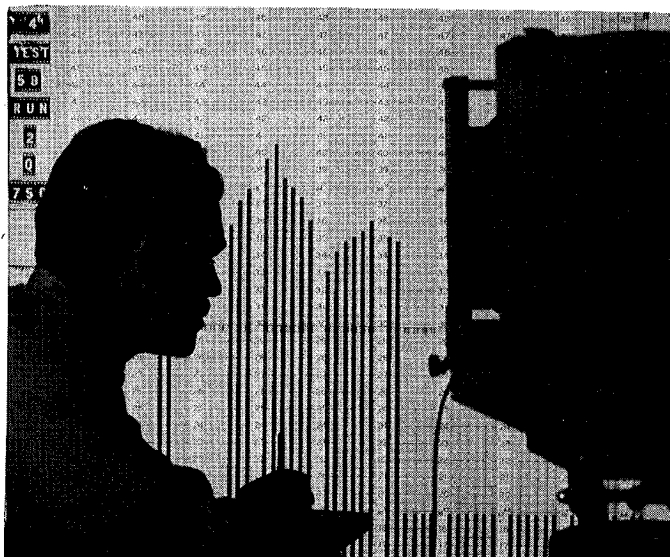
Two of Langley Laboratory's large high-speed wind tunnels were remodeled and repowered to handle transonic investigations. They were renamed the 8-Foot Transonic Tunnel and the 16-Foot Transonic Tunnel. In 1952, another 8-foot transonic tunnel was built, with a variable-density test section. The largest tunnel has two counter-rotating fans driven by two electric motors with a combined output of 60,000 hp.

These transonic tunnels can accommodate large scale models capable of extensive instrumentation with pressure orifices and resistance wire strain gages. Several smaller tunnels are used for transonic work, too.

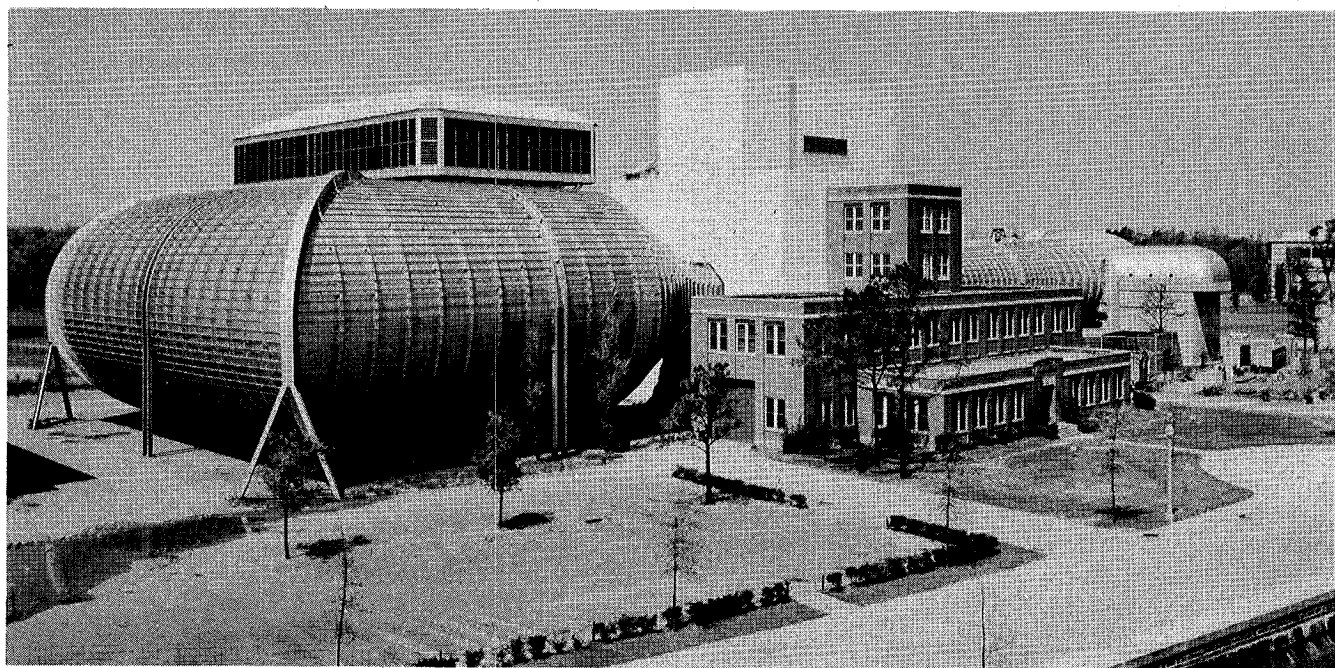
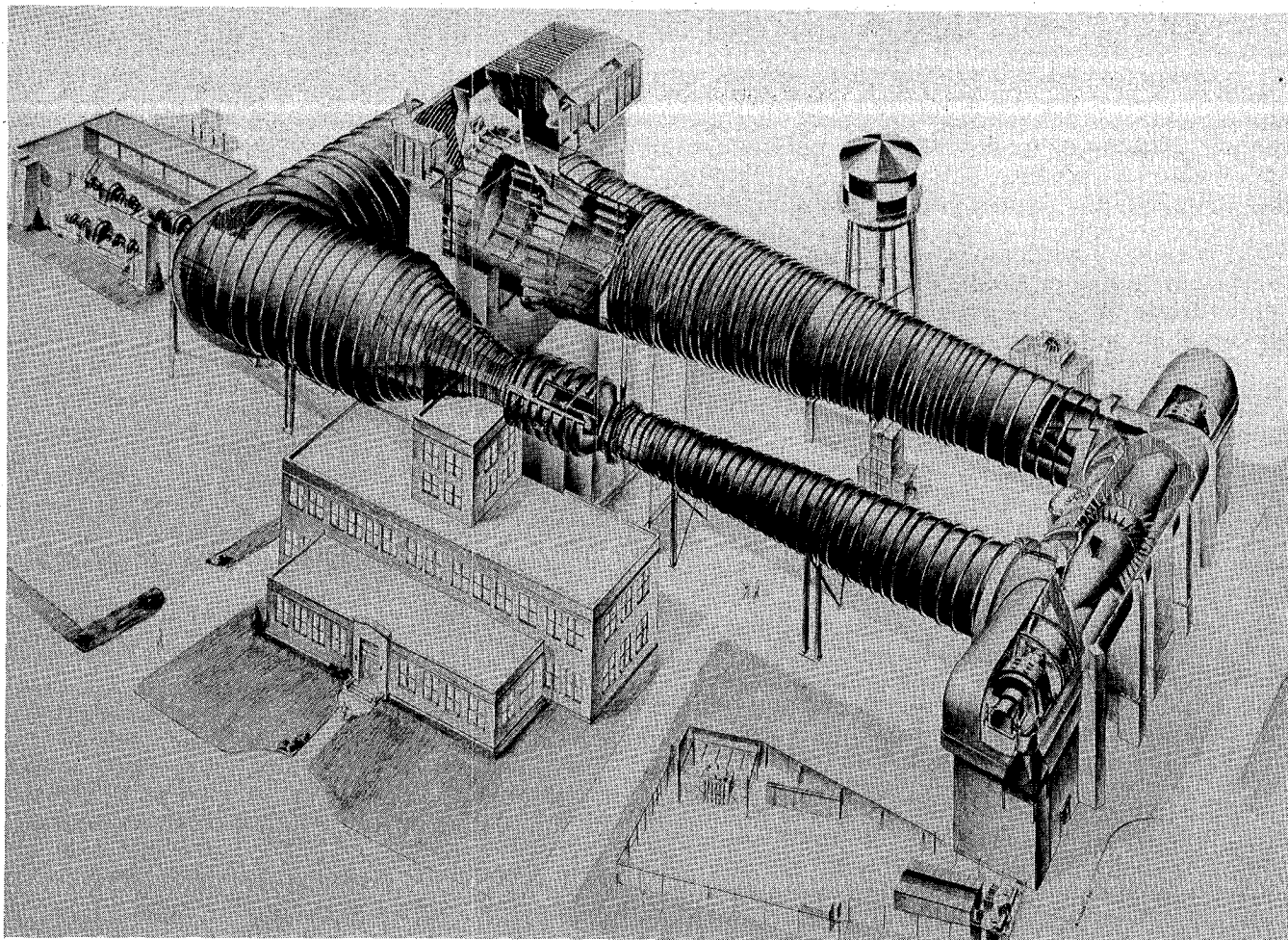
The use of wind tunnels, in addition to rocket-powered, free-flying models and actual airplanes, gives NACA scientists an opportunity to gather a great amount and variety of aerodynamic data in the transonic range under closely-controlled laboratory conditions.

Throughout the entire transonic zone, air flow through the test section is as accurate as can be maintained in modern tunnels designed for use on aerodynamic problems in other speed ranges. Tunnel air speed can be held precisely or varied smoothly through Mach number one. Detailed pressure measurements can be made and the air flow can be visualized by schlieren photography.

Wing shapes for high-speed airplanes, control surfaces, air inlets, propeller blades, and missiles are some of the subjects that can now be studied in transonic wind tunnels.



MANOMETER READINGS ARE PHOTOGRAPHED



16-FOOT TRANSONIC WIND TUNNEL AT LANGLEY. ABOVE, DIAGRAM OF THIS TUNNEL

SUPERSONIC AERODYNAMICS

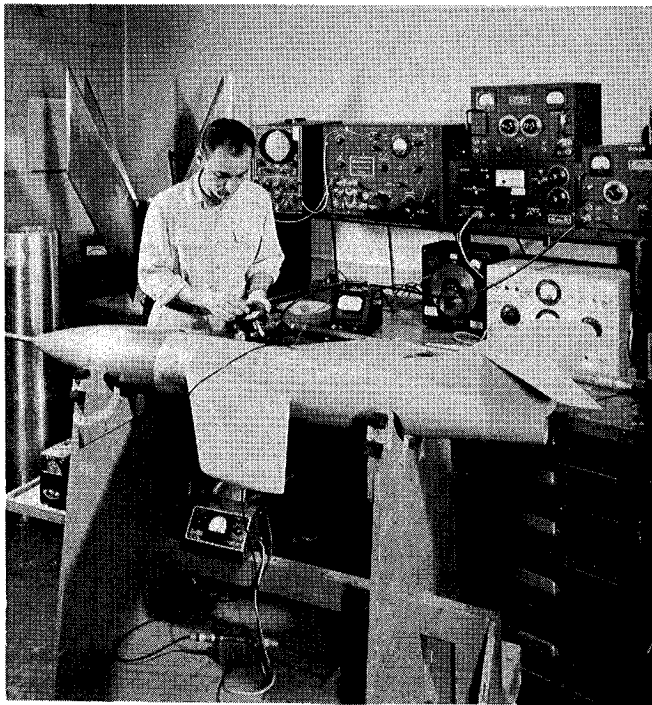
Severe aerodynamic problems arise when an airplane flies faster than about 600 mph. Compressibility effects such as excessive drag, loss of lift, and partial loss of control make it necessary to create radical new designs for transonic and supersonic flight. Buffeting and flutter become serious at high speeds.

New wing plan forms and airfoil sections are continually under study in NACA wind tunnels in an effort to discover shapes that will delay the onset of shock waves at very high speeds, or minimize the adverse effects of shock when it does occur.

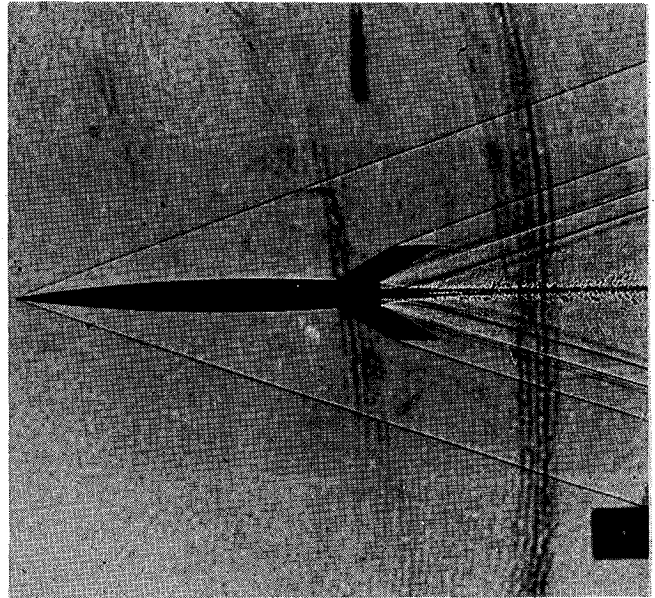
The supersonic airplane must be capable of flying with good stability and control at all speeds, from the low subsonic speeds required during take-off and landing to the highest supersonic speed attainable. It must pass safely through the dangerous transonic zone with its erratic, unpredictable air flow. The air flow around the airplane in each of these three speed regimes is radically different from that experienced in the other two, with the air forces varying greatly in size and distribution.

Despite this, the supersonic airplane must have low drag (air resistance) at all speeds. At the same time it must generate the lift required to fly and maneuver without experiencing buffeting forces dangerous to the airplane structure or the pilot. In all speed ranges, the delicate balance of forces must be maintained that permits stable flight with quick, accurate response to the pilot's controls.

An ideal solution of these problems in one speed range would often fail at higher or lower speeds. The ultimate solution is a matter of design compromise.



INSTRUMENTING SUPERSONIC FLYING MODEL



SHOCK WAVES AT 2,500 MPH

All the NACA laboratories carry on extensive research in supersonic aerodynamics. The Ames Laboratory was designed primarily for supersonic and high-speed studies, although it has important subsonic facilities, too. At Langley, one division operates the supersonic wind tunnels, another uses rocket-propelled models in free flight. The supersonic tunnels at Lewis handle matters related to jet and rocket engines, such as the shape of air inlets, turbine blades, and combustion chambers.

More than a dozen supersonic wind tunnels, all designed by NACA engineers, are now in operation. In addition, there are numerous "blowdown jets" with test sections ranging from 3 inches square to 18 inches square. These small test jets are not capable of continuous operation, but they can be run at supersonic speeds for short periods, some hitting Mach 4.5.

The principal methods of studying supersonic flows - in wind tunnels, in blowdown jets, with rocket-powered flying models, and by using piloted research airplanes - are all closely related and complement each other. Wind tunnels claim the major share of research effort and facilities, since they offer the most convenient method of conducting supersonic investigations under controlled conditions.

NACA scientists are also investigating aerodynamic problems in the hypersonic speed range, which is defined as five times the speed of sound or faster. Such information is already needed for the design of tomorrow's guided missiles. At the same time, even higher speeds are being studied.

The three NACA laboratories together have most of the world's largest and fastest supersonic wind tunnels. The largest, with a test section 8 x 6 feet and air speeds up to twice the speed of sound, is located at Lewis Laboratory in Cleveland. All three laboratories have smaller tunnels designed for higher speeds, including hypersonic speeds.

Three large supersonic wind tunnels that will be used extensively by aircraft manufacturers for development testing of tomorrow's tactical aircraft and guided missiles are under construction at the Langley, Ames, and Lewis Laboratories. Construction of these new facilities was authorized by Congress as part of the "unitary wind tunnel plan," with \$75,000,000 being appropriated for the purpose.

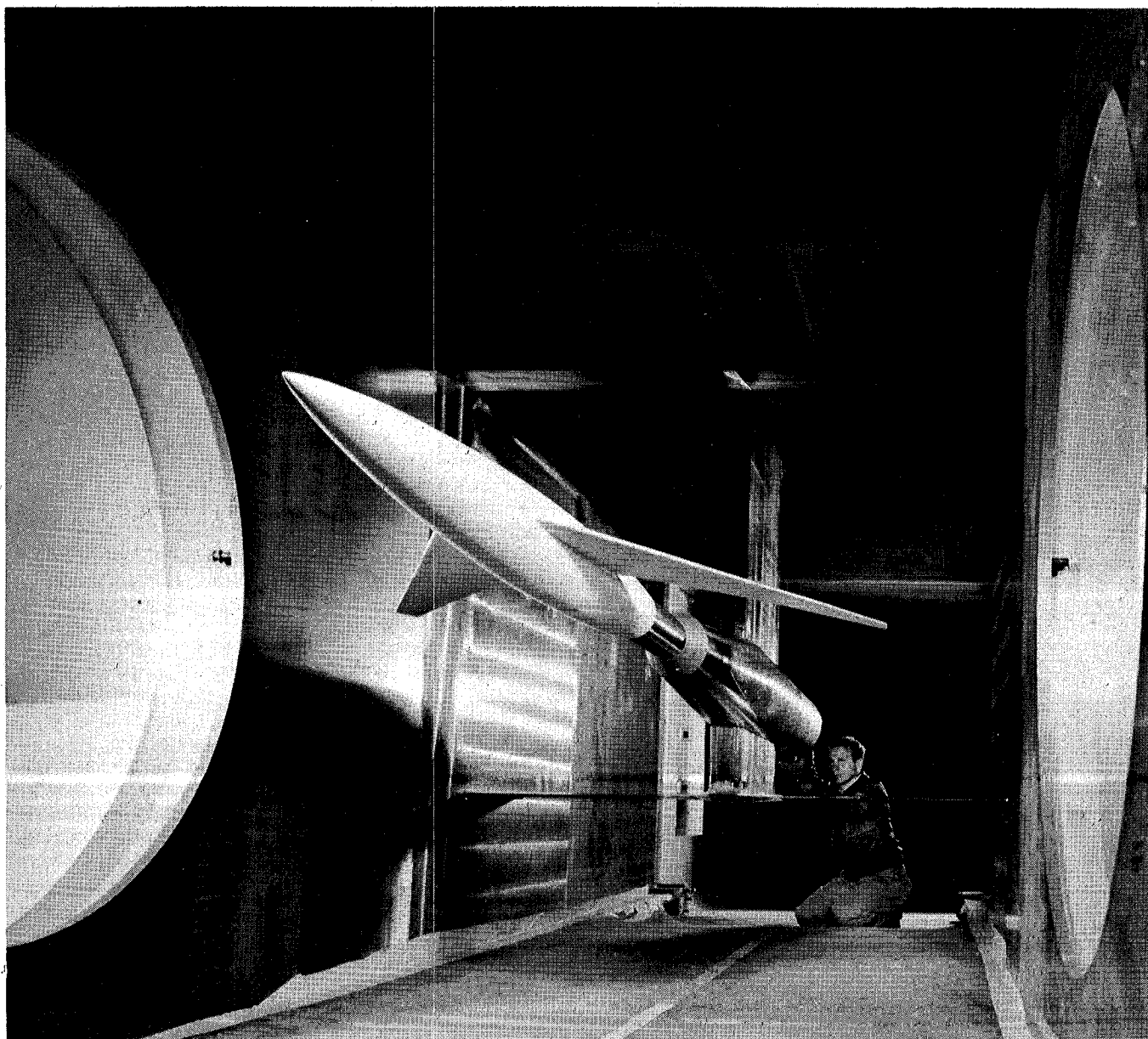
The three new tunnels will be used primarily for development work - for testing and improving specific new airplanes - in contrast to the broad, fundamental research carried on by NACA, which is not aimed at improving any individual plane.

The Gas Dynamics Laboratory and Cascade Aerodynamics Laboratory were completed at Langley in 1952.

Both have several very fast test air jets devoted to supersonic work. The Gas Dynamics Laboratory has test equipment capable of simulating flow conditions that an airplane or missile would encounter flying at several times the speed of sound and at extremely high altitudes.

Research on air induction and internal flow is yielding valuable data for the design of more efficient air ducts, one key to better jet engines and faster planes. In a fighter plane, as much as three tons of air must be crammed through the intake every minute to feed the hungry jet engine.

High-speed propellers, which first posed the problem of compressibility when their blade tips exceeded subsonic speeds several years ago, are still studied because of their application to fast fighters and bombers.



MODEL IN TEST SECTION OF 6 x 6-FOOT SUPERSONIC WIND TUNNEL AT AMES

STABILITY AND CONTROL

Stability and control problems have troubled aircraft builders since the first gliders and flying machines took to the air. Some of the NACA's first studies were pointed in this direction, both in wind tunnels and in flight research with biplanes. Report No. 1 dealt with stability problems.

The rapid increase in airplane size, power, speed, and wing loading has required continuing research in stability and control, with every solution followed by more complex problems. As a result of this NACA research, manufacturers have learned how to design better wings, tails, ailerons and spoilers.

In recent years, stability and control problems have been multiplied ten times by the trend toward very high flying speeds. They have become of critical importance in the design of high-speed planes. Not all the subsonic problems had been solved when NACA was called upon to extend its investigations to transonic and supersonic speeds, where many new difficulties arose.

Not only higher speeds, but new configurations, caused these control problems. Thin, swept wings, for example, required a new approach.

In other words, the design advances necessary to enable flight at the higher speeds in turn made more difficult the stability and control problems.

The provision of adequate stability for modern fighters, bombers, and big transports, with their high wing loadings, is a constant challenge to the designers. The problem is exaggerated at high altitudes, where the thin air makes wings and controls less effective.



STABILITY TUNNEL HAS CURVED WALLS

Very large or very fast airplanes encounter so much air pressure against the control surfaces that some method must be found to make it easier for the pilot to move the controls. Many military planes and transports have aerodynamically balanced controls, originated by NACA, to take advantage of the air forces instead of fighting them. Some of the air passing around the controls is made to assist the pilot in deflecting them further.

Power-boost systems for operating the controls hydraulically also are evaluated by NACA scientists. The design of these power-boosted control systems requires careful matching of their characteristics with the aerodynamic peculiarities of the airplane.

In addition to the more or less conventional airplanes, helicopters and convertiplanes present numerous problems in stability and control.

Much of the NACA's stability and control work is done at Langley Laboratory in three specialized wind tunnels and two 7 x 10-foot tunnels. But the subject is a broad one, invading numerous other wind tunnels at Langley and Ames, the flight research divisions of both laboratories, and the two field stations.

The specialized wind tunnels are called the Free-Flight Tunnel, Spin Tunnel, and Stability Tunnel.

In the first, dynamic models can be flown by remote control to study flying characteristics without endangering an actual airplane and pilot.

Spinning characteristics of an airplane can be predicted from the behavior of its dynamic scale model in the Spin Tunnel. Most American fighter planes have been tested there and generalized studies have been made with models representing bombers, transports, and personal planes.

The Stability Tunnel, which has two interchangeable test sections, simulates conditions encountered in flight maneuvers while the model remains stationary, connected with the balance system. Turning or rolling flight can be simulated by imparting a curving or rotary motion to the air stream.

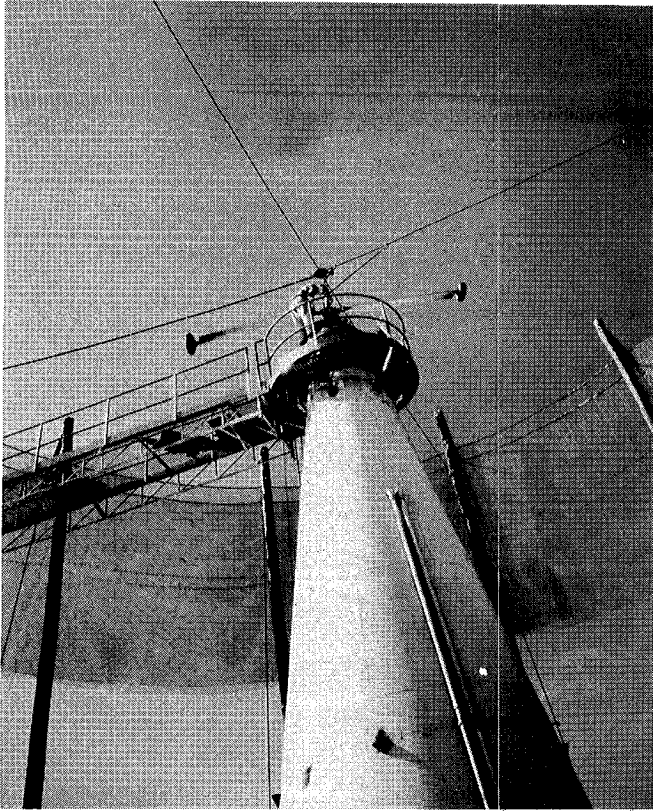
One of the 7 x 10-foot tunnels can be operated at speeds from zero to 300 mph; the other runs close to the speed of sound. Some unusual testing techniques, such as dynamic mounting of models and use of a "transonic bump," have been developed for these wind tunnels. The bump, which creates faster air flow around the model, is used in the high-speed tunnel. Stability tests in some large wind tunnels require a rolling balance that permits a wing or complete airplane model to roll freely, or another type of mount that permits the model to pitch.

Control methods developed in wind tunnels are tried out in actual flight by NACA test pilots, using standard airplanes with appropriate modifications.

The study of handling qualities of many types of airplanes and helicopters is one of the basic research programs carried out by using actual aircraft.

Pilotless aircraft are used extensively for investigations of dynamic stability and control effectiveness. Missile configurations, as well as advanced types of military planes, figure prominently in the pilotless aircraft program.

HELICOPTERS



JET ROTOR ON HELICOPTER TOWER

NACA scientists have been studying rotary wing aircraft since the autogiro came into use more than 20 years ago. Research efforts first emphasized improvement of performance and prevention of catastrophic vibrations. More recently, the improvement of stability and control has been the paramount problem. At present, emphasis is shifting toward air loads information permitting more efficient structural design, and toward acquiring the knowledge essential for design of types permitting higher maximum speeds.

With the assistance of the basic studies made by the NACA, the manufacturers have overcome serious performance, vibration, and stability problems to the extent that helicopters in both military and commercial use have given convincing demonstrations of their unique capabilities, versatility, and reliability.

Obviously, if helicopters can be made safe for flying in fog and darkness, their usefulness will be greatly extended. Although such flights are often made experimentally, and although stability improvements have paid off handsomely, troublesome problems remain - particularly at low speeds. As a consequence, helicopters generally cannot be operated if the pilot cannot see the ground.

NACA pilots, trained to distinguish basic handling qualities difficulties from the more superficial ones, take an active part in the Flight Research group's studies of stability and all-weather flying. They have flown most types of helicopters in an effort to assess the most common problems. One military model has been rigged to simulate "blind flying" conditions and,

by means of autopilot components, has been provided with adjustable stability and control characteristics. A flight investigation is underway to determine what changes in stability characteristics will be most helpful. In such a project the pilots' opinions, together with time histories showing the ease and accuracy of standard maneuvers, are correlated with measured stability characteristics.

The study of loads assumes greater importance as designers attempt to increase the helicopter's payload and forward speed. Vibration, which has always been a serious problem, becomes worse at higher speeds, shortening the life of rotor blades by fatigue and increasing maintenance difficulties. To avoid excess weight, helicopter designers must know the magnitude of applied loads and the ability of the structure to withstand these loads. The dollar value of such knowledge increases with the increasing helicopter production rate.

Statistical information on flight loads and associated operating conditions, needed for stress analysis and the calculation of rotor fatigue life, is obtained by installing an automatic recording device in a number of military and commercial helicopters. Normal acceleration, airspeed, altitude, and rotor rpm are recorded for analysis by NACA.

In 1946, the Helicopter Test Tower was built at Langley Laboratory to permit study of rotor performance, control, and vibration characteristics at wind speeds representing hovering flight. Experimental rotor blades using new shapes, materials, or construction methods can be employed in these tests without incurring the risks of flight testing such articles.

Some rotors are whirled at high tip speeds to study the effects of compressibility on rotor performance and control, and thus provide a basis for new designs involving higher tip speeds. Other rotors, driven by ram or pulse-jet power plants located at the blade tips, are tested on the tower to determine the most significant problems of such drive systems, and to indicate promising avenues of solution.

While the Tower covers only zero or low wind speed conditions, the Full-Scale Wind Tunnel, which devotes half its running time to helicopter research, covers speeds up to about 100 miles per hour, and some use is made of tunnels with much higher speeds. The Full-Scale Tunnel's large open-throat test section makes it well suited to the investigation of aerodynamic characteristics of various rotor configurations, including coaxial, tandem, and side-by-side arrangements.

Each configuration adds some problems of its own. For example, the use of two or more rotors on larger machines introduces complications caused by mutual interference effects.

The helicopter research is centered at Langley, and makes use of many of the research facilities available there. In addition to those already mentioned, facilities currently handling helicopter projects include the Vibration and Flutter Laboratory, the Stability Tunnel, and the Low-Turbulence Pressure Tunnel.

AIRCRAFT STRUCTURES AND LOADS

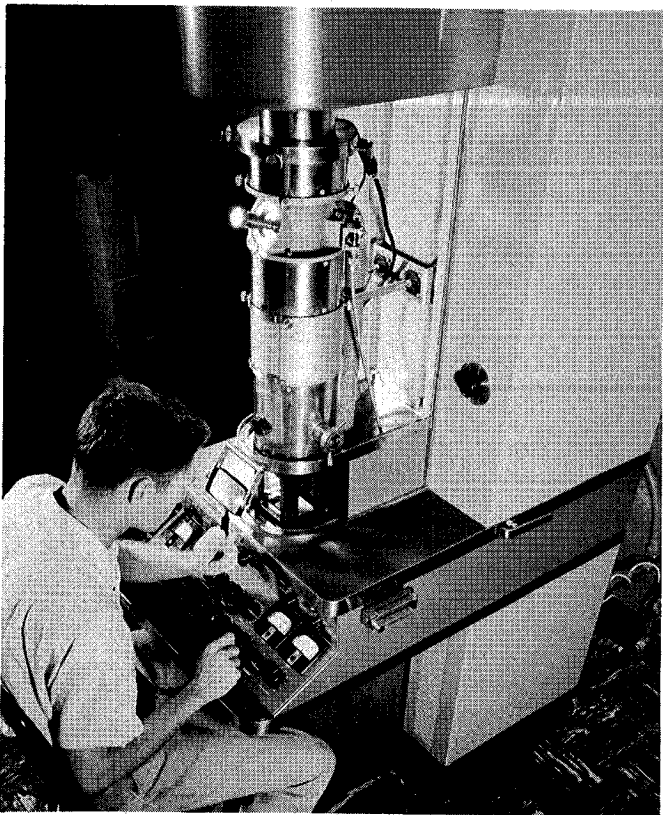
Every part of an airplane must be strong enough but as light as possible. Excess weight imposes severe penalties on performance. In military aircraft, these penalties take the form of reduced speed, range, bomb load, or maneuverability.

Commercially, one pound of weight saved may be worth hundreds of dollars in payload during the life of a single transport plane.

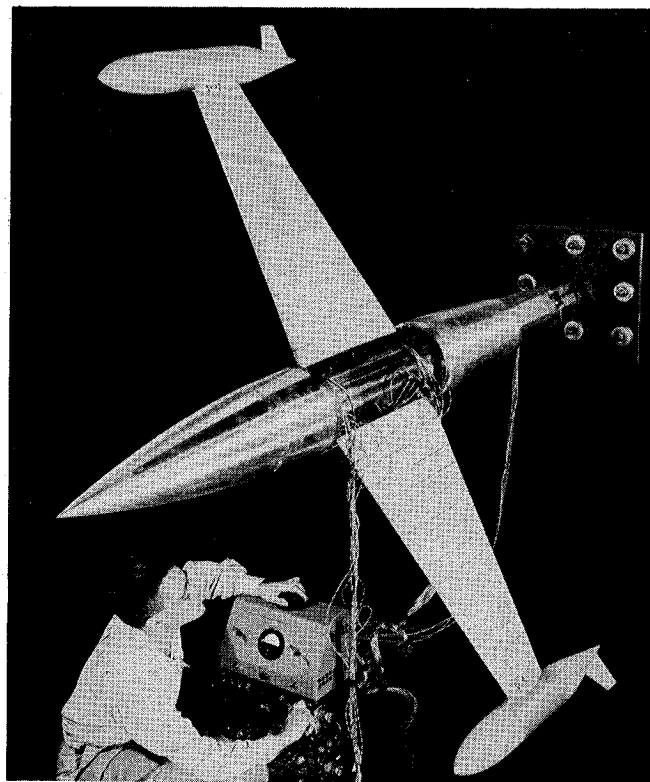
Research efforts to cut down the weight of military aircraft are intensified because of the knowledge that gains here may well make the difference between superiority of performance, over a potential enemy, and second-rate equipment.

There may be no harm in building a railroad car many times as strong as necessary, but such extra ruggedness cannot be built into an airplane. The performance penalty places a practical limit on the weight, and thus on the strength, of an airplane. Ordinarily, the wings and principal parts of an airplane are designed to be about 50 percent stronger than will be required by the most severe operating conditions anticipated.

Despite the demand for weight reduction, the airplane must be strong enough to withstand the loads applied during flight operations, whether these loads arise from maneuvering flight, rough air, or landing.



ELECTRON MICROSCOPE USED FOR METALS



INSTRUMENTING MODEL FOR FLUTTER TEST

Structural research has two aims: To decrease the weight and increase reliability of the aircraft structure. But first, the forces imposed upon aircraft structures must be known quantitatively to a high degree of accuracy.

In an effort to match strength with loads, the NACA is devoting considerable research effort to the solution of such problems as these: What is the magnitude and distribution of the applied loads? How are these loads affected by flight operational procedure? How strong must the structural material be to withstand these loads? How should this material be distributed for maximum load-carrying efficiency? What uses can be made of new metals and materials? What about the fatigue life of these materials?

Military planes designed for very-high-speed or supersonic flight have introduced new problems in evaluation of the magnitude and distribution of dynamic loads, both in gusty air and in maneuvers. In the commercial field, the trend toward large transports has resulted in a heavy investment per airplane calling for high utilization, with consequent danger of fatigue of metal alloys used in the framework. Very large and heavy airplanes, both military and commercial, need strong landing gear to withstand the severe shock of landing. Every pound of this gear is dead weight during the flight.

NACA's research in the field of aircraft construction is expanding to cover the complex problems introduced by very-high-speed flight. Aircraft structures must now be designed to withstand the high temperatures resulting from aerodynamic heating at supersonic

speeds, plus the attendant complications brought on by increased air loads. The need for thinner wings and slenderer fuselages, also dictated by high speed, introduces flutter and dynamic response problems so difficult that they cannot be solved by known theoretical means alone, but must be studied in all their complexities by dynamic models. The need for structural materials with higher stiffness and higher strength at elevated temperature is apparent.

The work is divided into four sections: Aircraft structures, aircraft loads, vibration and flutter, and aircraft structural materials.

The closely related studies of aircraft loads and structures are assigned principally to two divisions at Langley Laboratory, the Dynamic Loads Division and the Structures Research Division. A great deal of loads research, however, is carried on in other divisions. For example, the Flight Research Division investigates the loads imposed on an airplane in maneuvering flight. Much of the wind tunnel work can properly be called loads research, too, particularly where it yields information on pressure distributions, division of aerodynamic load between various parts of the airplane, and loads on high-lift devices and external stores.

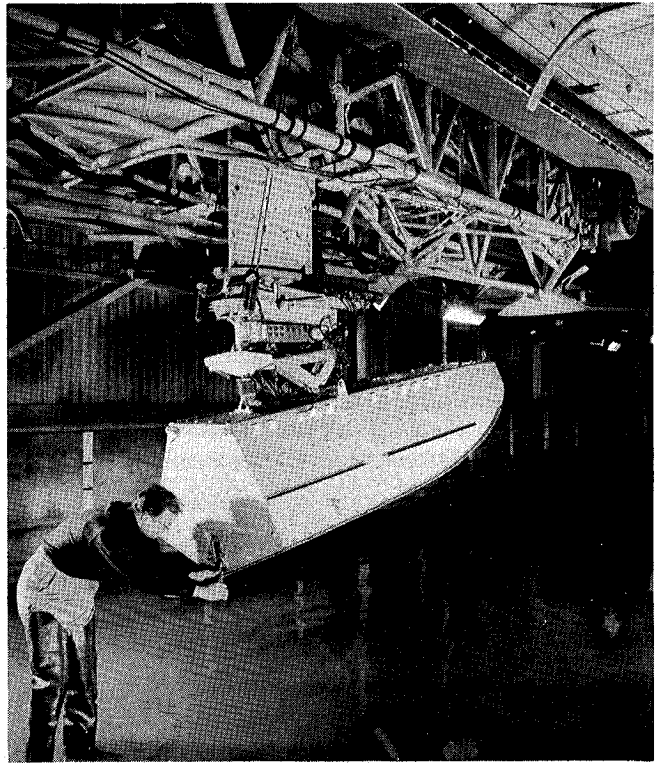
Solutions to loads and structures problems are sought by both theoretical and experimental means. The experimental facilities of the Dynamic Loads Division include the Gust Tunnel, Impact Basin, Flutter Tunnel, and Vibration and Flutter Laboratory. All phases of structures work are carried on in the Structures Research Laboratory.

In the Gust Tunnel, dynamic flying models up to six feet in span can be catapulted through artificial gusts of various shapes and velocities. This tunnel reproduces controlled and measured up-or-down drafts. Stroboscopic photographs of the model, which usually flies between 60 and 100 mph, show how much the model is deflected from its course. Instruments inside the model indicate what effect such a gust would have on a full-size airplane.

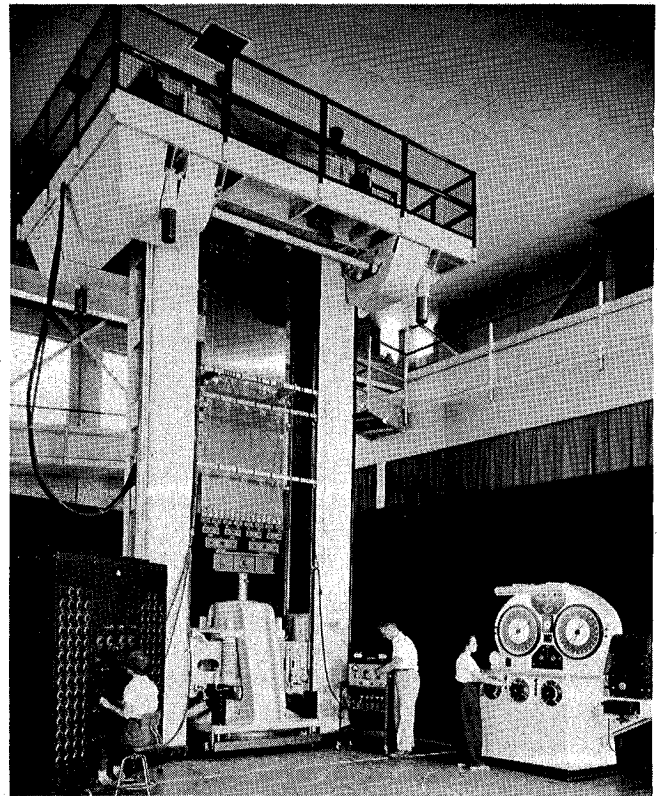
The Impact Basin, which is equipped with a wave-maker, is used for accurate measurement of landing forces and pressures on float and hull bottoms at speeds up to 70 mph. These data are used in hull stress analysis. The impact absorbed by landing gear can be measured by substituting a long concrete platform for the water.

The Structures Research Laboratory has equipment for testing metals used in aircraft construction for material properties, particularly at high temperatures, and for fatigue. Tests for stability and stress distribution can be conducted on wings, fuselage sections, or their structural components such as cylinders, columns, and panels.

Four testing machines - the largest with a capacity of 1,200,000 pounds - are used to exert the great stretching or compressive forces required for structural testing at large scale. One machine designed by NACA can apply combined loads, such as a twisting or bending force combined with either tension or compression. Numerous machines are available for fatigue testing. An electron microscope is used for study of the crystalline structure of metals.



PREPARING FOR TEST IN IMPACT BASIN



"MILLION POUND" MACHINE IN STRUCTURES LAB

HYDRODYNAMICS

The NACA has been actively engaged in studying seaplane problems, particularly those connected with hull design, take-off, and landing, since its first towing tank was constructed at Langley Field in 1931.

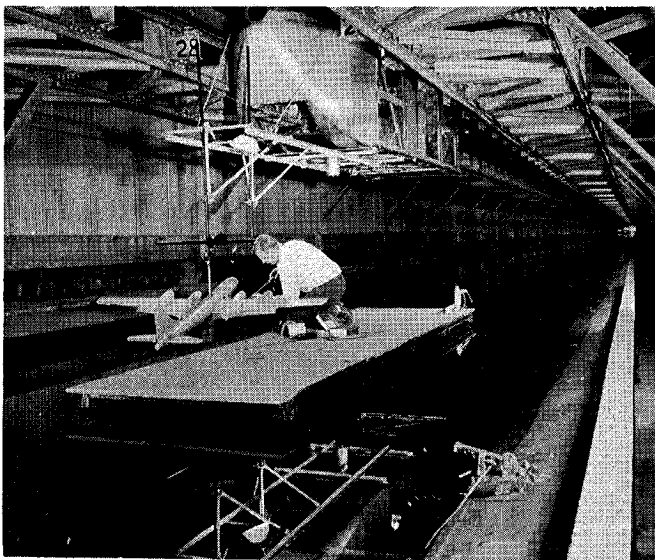
The Hydrodynamics Division conducts fundamental research on the proportions and shapes of hulls and floats. A systematic investigation of hull proportions led to the significant conclusion that making flying-boat hulls longer and slimmer would reduce drag in the air, structural weight, and landing impact loads. This principle has been applied and proved in the Navy's postwar seaplanes.

The aerodynamic refinement of flying boat hulls now appears to have been carried almost to a practical limit with the development of the planing-tail hull. This long, slim, low-drag hull has a forebody shaped like an airfoil.

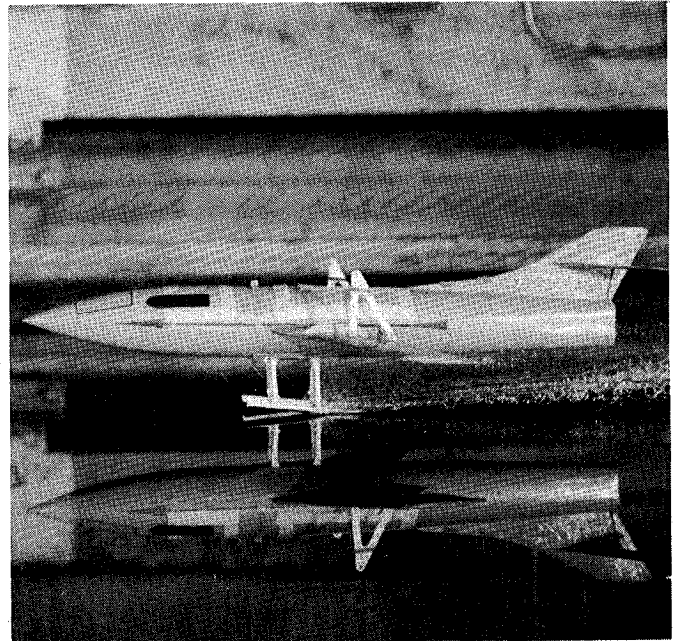
Two revolutionary developments, however, promise great improvements in seaplane design and utility. One is the application of jet engines to seaplanes, eliminating the cumbersome propeller, which had to be placed out of reach of the waves. The other is the development of the hydro-ski principle, which may release the flying boat from its speed handicap caused by the large hull required for take-off and landing.

NACA's research on hydro-skis has important military significance. This device is expected to make any smooth body of water, snow, or even wet sod a potential landing field for fast jet planes. Not needing a floating hull, the ski planes would possess the aerodynamically clean lines of a landplane.

The Hydrodynamics Division conducts its studies in two long towing tanks, each equipped with a speedy electric carriage from which a model can be suspended. One tank is 2,900 feet long (over half a mile), 24 feet wide, and 12 feet deep. The other is 1,800 feet long, 18 feet wide and 6 feet deep. The carriages provide



PREPARING BOMBER MODEL FOR DITCHING RUN



TRANSONIC MODEL WITH HYDRO-SKIS

towing speeds up to 60 mph, which are sufficient to make a scale model take off from the water and "fly" at scale speed. Conversely, the model can be made to simulate a landing.

As the model is towed on the surface, its stability, controllability, water resistance, and spray characteristics are recorded by instruments and motion pictures. Scale-size waves can be made in the tanks, and electrically-driven propellers on the models give scale power effects.

Tests made with models in the towing tanks have proved highly reliable in evaluating the take-off and landing qualities of seaplane designs and proposed modifications. Many Navy seaplanes have been improved by such tests, particularly in respect to hull shape. Recent research on seaplanes has been directed toward improving the flight and rough-water-operation characteristics of hulls.

Design details now in use which evolved from this basic research include strips to keep spray out of propellers, ventilation of the hull "step" to improve stability and handling qualities, increase in afterbody length to reduce violent motions in waves, and sharpening the vee bottom of the hull to reduce landing impact.

The "ditching" of landplanes, which first became a major operating problem during World War II, has been studied by NACA for several years. Flying scale models were catapulted into the towing tank, with movie cameras recording the angle at which the model plane struck the water, spray formation, skipping, deceleration, and tendency to nose under. Information was assembled on ditching experience with actual airplanes.

As a result of this research, pilots were instructed how to bring down a disabled transport, bomber, or fighter on the water with minimum danger to personnel, and aircraft manufacturers were told how they could build better ditching characteristics into their planes.

SUPERSONIC PROPULSION

The spectacular increases in speed obtained during recent years can be continued only if means are found to obtain the tremendous powers required by future supersonic aircraft and missiles.

The primary objective of the research teams at the NACA Lewis Flight Propulsion Laboratory is to obtain the new knowledge necessary to increase the power and efficiency of supersonic propulsion systems. The specific types of propulsion system under investigation include the turboprop, turbojet, ram-jet, and rocket engine. The NACA has the organization, laboratories, and research equipment to stimulate and further the most advanced thinking on supersonic propulsion systems.

The facilities include six small wind tunnels which permit the investigation of small scale models at Mach numbers from 1.85 to 7.0. The investigation of the combustion characteristics of model ram-jet engines can be conducted in five of these wind tunnels.

Supersonic propulsion systems must be investigated with the complete aircraft configuration. The 8 x 6-Foot Supersonic Wind Tunnel operates at a Mach number range from 1.5 to 2.0. The tunnel is used to study the combustion characteristics of model ram jets, the pulsations associated with some types of ram-jet combustion, flame blow-out at high speeds, the performance of supersonic inlets for ram jets and turbojets, and the drag of supersonic engine installations.

The Engine Research Building at Lewis contains nearly 100 different research laboratories and test cells in which research is conducted at sea-level and altitude

conditions on small-scale and full-scale compressors, compressor and turbine blading, combustion chambers, turbines, afterburners, fuel-injection systems and controls, afterburner fuel systems, flame holders, and variable area exhaust nozzles.

The investigations of full-scale turbojet and ram-jet engines under high-altitude conditions are conducted in two 10-foot-diameter altitude chambers in the Engine Research Building, the 20-Foot Altitude Wind Tunnel, and two new 14-foot-diameter altitude chambers in the Propulsion Systems Laboratory. Turboprop engines with flight propellers are investigated in the 20-Foot Altitude Wind Tunnel.

The combustion-air supply, refrigeration, and exhaust systems of all the laboratories are interconnected so that the full capacity of the service supply systems can be made available to any research facility as required. The service systems supply combustion air at temperatures from -70°F to 600°F , pressures from 2 to 450 pounds per square inch, and exhaust at a minimum pressure simulating 60,000 feet altitude. The nerve center for the control and dispatching of these services is the Central Control Room in the Engine Research Building. Electric power is dispatched to all facilities from the control room in the Research Equipment Building. The Lewis Laboratory is the second largest consumer of electrical power in the Cleveland area.



RAM-JET MISSILE IN 8 x 6-FOOT SUPERSONIC TUNNEL AT LEWIS FOR AIR INLET STUDY

THERMODYNAMICS

The thermodynamic research conducted by the NACA in relation to propulsion systems includes basic studies of the thermodynamic properties of the working fluids used in aircraft engines; heat transfer, concerned with all cooling and heating problems; and cycle analysis, which seeks to evaluate the performance of new engine types and the effect of various combinations and refinements of components on over-all propulsion system performance.

PROPERTIES OF GASES. The analytical study and design of efficient high-performance aircraft jet engines requires an understanding of the thermodynamic properties of the working fluids in steady flow processes. Thermodynamic tables of the properties of any combination of carbon, hydrogen, nitrogen, and oxygen systems, for example, are being computed to enable accurate calculation to be made of jet engine combustion and flow processes.

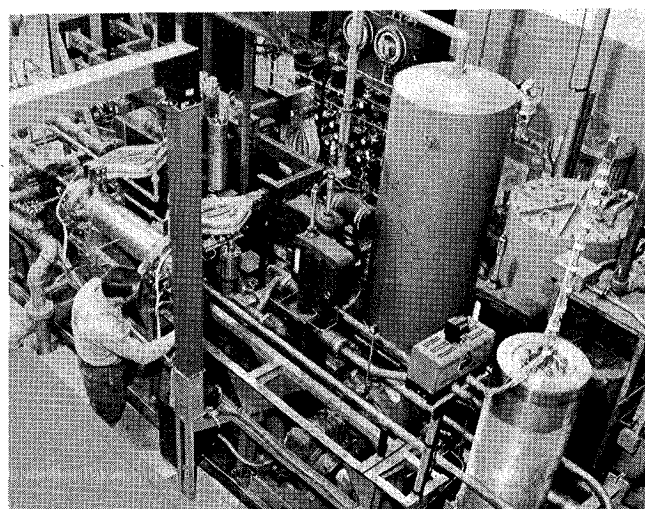
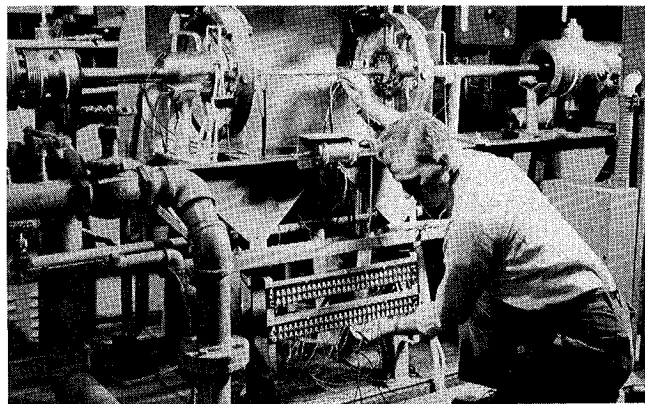
HEAT TRANSFER. All problems of exchange of heat between fluids and materials come under the heading of heat transfer. Some of the most important research conducted by the NACA in the past has been in the field of piston-engine cooling. Heat-transfer characteristics under conditions more severe than those described in existing literature must now be determined and the generalized equations derived to aid in the design of efficient cooling systems for rockets and gas turbines.

Gases and fluids under very high temperature and sometimes under supercritical pressures are passed continuously through electrically heated tube elements of various cross sections and internal roughness to determine the nature of the heat-transfer process at high heat fluxes.

Improved understanding of heat transfer at higher temperatures and heat flux rates will add greatly to the power and compactness of future engines. A number of heat-transfer laboratories of different types are located in the Engine Research Building.

Thermal ice protection of aircraft frontal surfaces and engine inlets depends on knowledge of heat-transfer rates and efficient heat exchangers. Design knowledge of compact, large-capacity heat exchangers was a necessary prerequisite to the development of the thermal ice-prevention systems now coming into general use. Continued thermal ice-prevention research is being carried on in relation to jet-engine inlet and compressor blade icing.

The problem of providing economical cyclical de-icing by pulsing the flow of high-pressure hot gases bled from turbojet engines through efficient double-skinned heat-transfer systems in the thin wings of high-performance airplanes is being actively investigated analytically and by experiments in the Icing Research Tunnel at Lewis. The effect of electrical or hot-gas systems of de-icing on over-all airplane performance is an essential question that is studied analytically.



TWO SETS OF HEAT-TRANSFER APPARATUS

CYCLE ANALYSIS. Profitable expenditure of research effort on new engine types and engine components must be planned in relation to probable immediate and long-range gains. Analyses of various engine cycles aid in defining necessary fields of research. Cycle analysis also maps the probable range of application of engine types on the basis of performance, weight, size, and operating characteristics, and must be restudied periodically as progress in experimental research or changes in military strategy dictate new emphasis on propulsion requirements.

Careful evaluation of all engine processes is needed to determine the compromises necessary in engine components in relation to weight, size, speed, and efficiency. For example, promise of advances in performance and fuel economy lies in new combinations of heat regeneration and reheat. Maximum gains up to 60 percent in take-off thrust and of approximately 200 percent in operation at supersonic speeds are being shown analytically for turbojet thrust-augmentation systems. Emphasis in the analysis of engine cycles is focused mainly on the performance of such a propulsion system as installed in an aircraft designed for a specific mission.

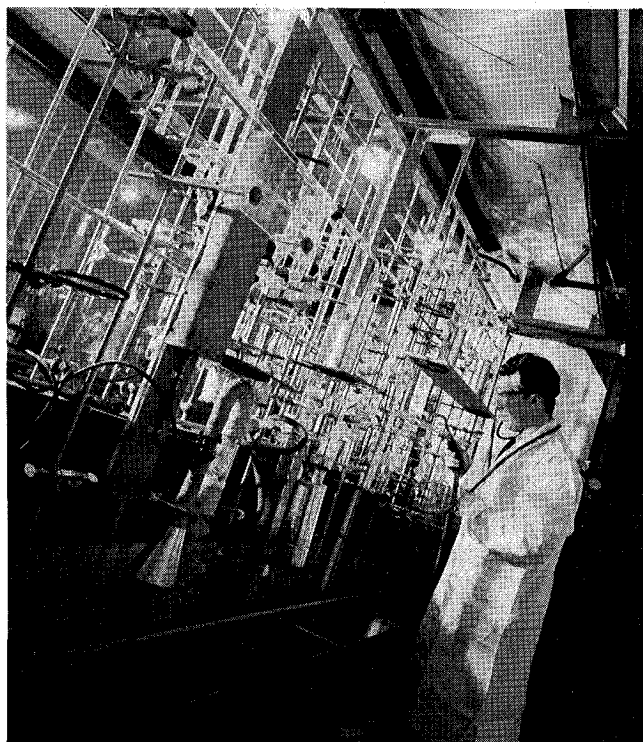
FUEL CHEMISTRY

The adaptation of conventional hydrocarbon fuels to turbo-jet, turbo-propeller, and ram-jet engines poses many difficult problems. Although the basic principles of combustion for these engines are similar, the physical environments in which the combustion process occurs may differ significantly. For this reason research is conducted to determine what compromises between fuel characteristics and engine design must be achieved to satisfy over-all performance requirements.

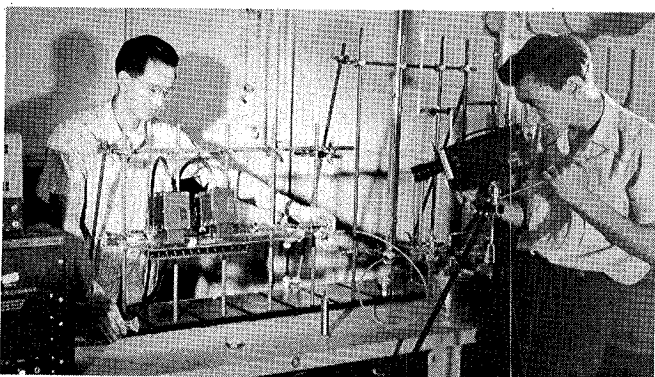
In addition to performance considerations of fuels, there are other practical problems that must be studied to insure the success of particular fuels in aircraft. These problems include factors relating to aircraft reliability, aircraft safety, and logistics.

Most jet engines are installed in high-speed aircraft which have very small fuselages and thin wings, greatly restricting the space available for fuel tanks. At Lewis Laboratory, an investigation is under way to find liquid fuels which will occupy less space for a given energy content than do conventional fuels. Such fuels would result in greater range for existing jet-engined aircraft or greater speed for new designs.

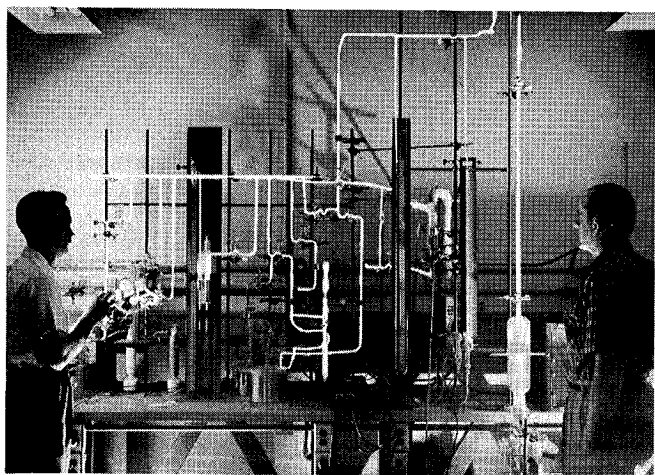
In the case of ram-jet engines designed to propel aircraft at supersonic speeds, attainment of long-range flight will depend on development of fuels giving energy releases in excess of those possible with fuels derived



CHEMIST IN FUELS LAB



MEASURING FLAME VELOCITY



SEEKING INFLAMMABILITY LIMITS OF FUELS

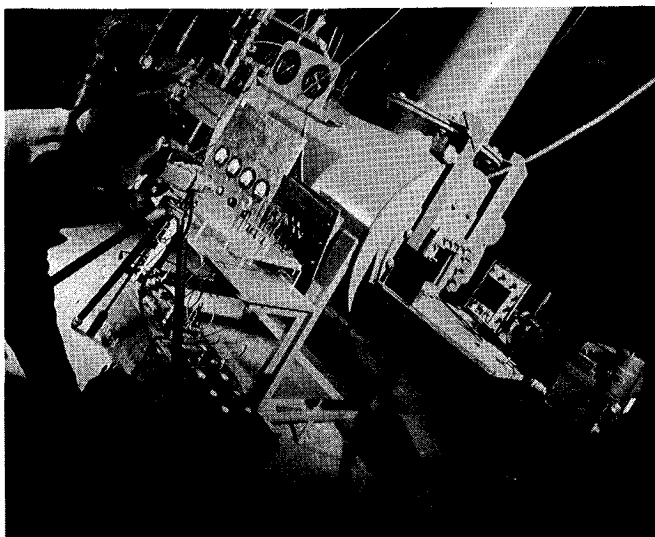
from petroleum. Here investigations must be conducted on metallic and other nonhydrocarbon fuels.

With increasing prospects for the use of rocket power, intensive research is in progress on rocket fuels that will provide greater thrust and greater endurance for increased range. In addition to these requirements, the fuels must have desirable handling properties. Experimental studies of rocket-propellant performance are usually preceded by theoretical analyses. These analyses provide a basis for comparing the performance of various propellant combinations prior to actual experimental study.

Research on other engine fuels is conducted in the Fuels and Lubricants Building and the new High Energy Fuels Laboratory, where chemical analysis and synthesis of new fuels is performed in correlation with combustion research. The objective is to gain basic knowledge of fuel structure and characteristics.

Research on fuels makes extensive use of the sciences of chemistry and physics. The Fuels and Lubricants Building contains well-equipped chemistry and physics laboratories where fundamental research is conducted on aircraft fuels and lubricants. Rare fuels, unobtainable commercially, are synthetically produced in glass-lined reactors and purified in three-story-high distillation columns. The laboratories are equipped with the latest in spectrographic apparatus, an electron microscope capable of 30,000 diameter magnification, special equipment for studying combustion, and other advanced research tools.

JET ENGINE COMBUSTION



MEASURING HEAT OF RAM-JET FLAME

The primary objective of combustion research at Lewis Laboratory is to determine the requirements for optimum combustion of fuel and air in the space allotted in the engine. In order to achieve this objective, it is first necessary to understand the fundamental mechanism of combustion, and second, to understand the transitions that must be made to these fundamental mechanisms in applying them to combustion in the actual engine.

This approach involves research conducted on simplified laboratory apparatus, on single tubular and segmental annular combustion chambers mounted in ducts, on fuel-injection systems, and on full-scale engine combustion chambers. The information obtained provides the design criteria upon which development of future engines may be based.

Among the facilities for the fundamental study of combustion are special types of apparatus for the measurement of flame properties such as burning velocity, quenching distance flammability limits, and ignition energy. Special cameras and optical systems for schlieren and shadow photography are available for the study of flames. Resistance thermometers and spectrographic equipment are available for the measurement of flame temperature. A portable hot-wire anemometer which may be used to measure both the scale and intensity of turbulence, as well as the local average velocity, is accessible. The aid of experienced groups for instrumentation problems, computing, and chemical analysis is also available.

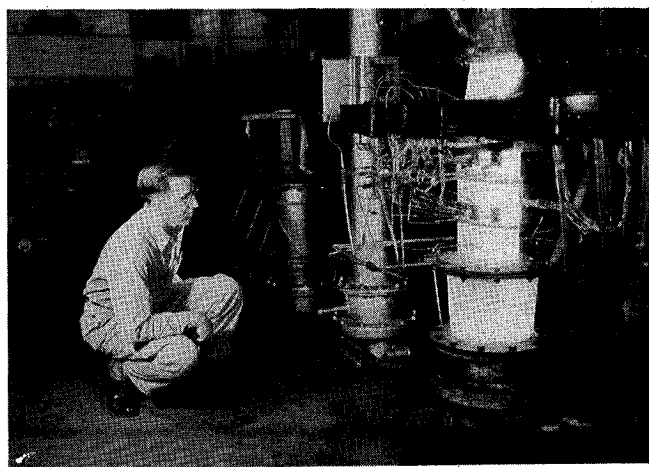
FLAME TUBE STUDIES. One of the most important processes in a jet-engine combustor is the propagation of flame into the unburned fuel-air mixture. A better understanding of the process may be obtained by a study of laminar flame speeds. Studies are carried out in tube apparatus to determine the effect of initial pressure and temperature on the limit of flame propa-

gation of pure hydrocarbons and mixtures. The injection and vaporization of fuel droplets are investigated under conditions similar to those encountered in aircraft combustion systems. An insight into the over-all mechanism of combustion is obtained from tube studies made with gaseous and liquid hydrocarbon oxygen-nitrogen fuel mixtures to determine minimum ignition energy, blow-off and flash-back limit, flame quenching distance, and flame speed.

CARBON FORMATION. The formation of carbon in the turbojet engine presents a number of operating problems. Carbon deposition on walls, fuel-injection nozzles, and ignitors affects combustion efficiency, altitude operational limit, and ignition characteristics of the combustor. The disturbed air flow and fuel spray patterns which result from carbon deposits frequently cause warping and burning of the combustor liner. The combustion research team makes studies to determine how the formation of carbon may be suppressed during the combustion process and the most efficient method of preventing smoke from appearing in the jet.

COMBUSTION CHAMBER. A concentrated study on a whole new range of combustion-chamber problems is required to obtain the increase in the quantity of heat release specified for future jet engines. Studies are made to obtain efficient combustion at air velocities above current design practice and with higher outlet temperatures. The effect of turbulence on flame propagation is determined and the results applied to full-scale engines.

The improvement of altitude starting characteristics of present jet engines is studied at Lewis with single, segmented, and full-scale combustors to determine the effect of fuel volatility, spark plug design, spark energy, and spark repetition rate on the minimum combustion chamber pressure at which reliable ignition can be obtained. The applicability to full-scale engines of improvements in combustion characteristics determined from experimental studies of segmented combustion chambers tested in ducts is determined by operating the full-scale combustion chamber in a jet engine.



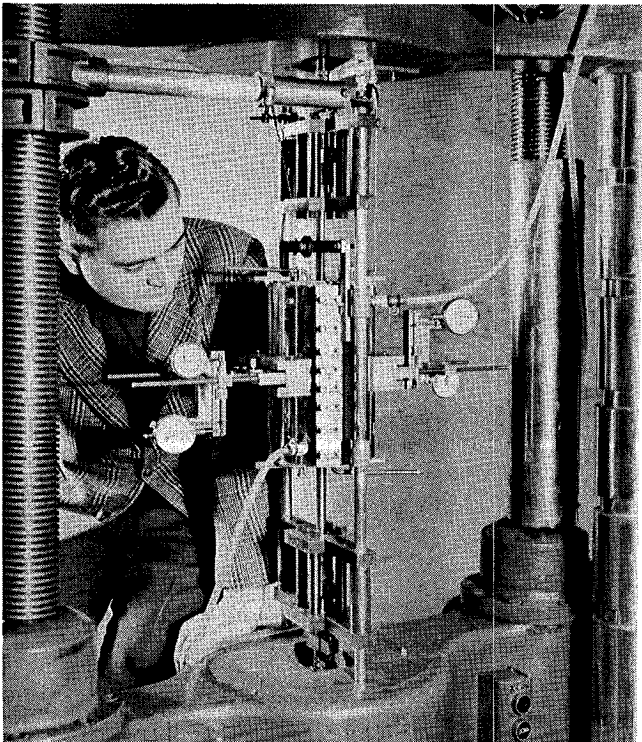
COMBUSTION CHAMBER RED HOT IN TEST

All aircraft engine designs could be greatly improved if the designer had a wider range of materials from which to choose, a more definite knowledge of the properties of materials, and better understanding of how these materials will behave under any given set of conditions.

For example, an increase in the operating temperatures of aircraft engines would increase the over-all power output from the unit. The advent of new high-temperature materials would place this goal within the designer's grasp. Again, if operating stresses in various engine components were accurately known, it might be possible to reduce appreciably the mass of these parts, thereby decreasing the total engine weight and improving the over-all aircraft performance.

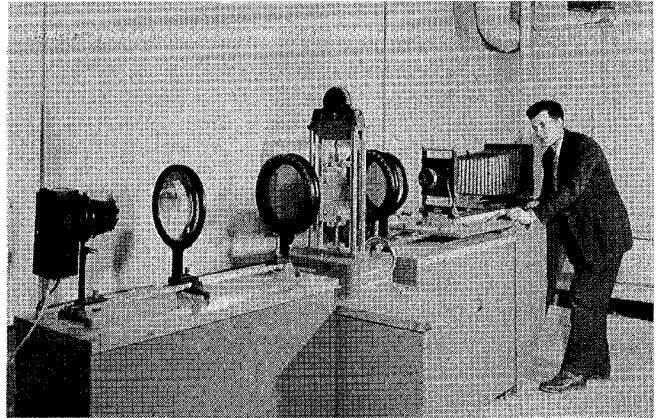
In order to improve current engines, an extensive program of evaluation of present high-temperature materials is being conducted at Lewis Laboratory. Fundamental research is under way on the basic reasons for the relative performance of heat-resisting materials in general, the mechanism of failure, the roles played by precipitated particles and mechanical and thermal treatments of materials, and the effect of protective coatings on turbine components. The development of new cermet materials is under way in an attempt to provide materials able to withstand higher engine operating temperatures and to conserve the supply of more critical elements in high-temperature materials.

The general goal of stresses research is to obtain a better understanding of how the strength of materials is influenced by loading conditions which are encountered in the jet engine and to devise ways and means of reducing stresses to safe limits. Studies are made of



HIGH-TEMPERATURE STUDY OF METALS

MATERIALS AND STRESSES



POLARISCOPE USED IN STRESS STUDIES

the fundamental influence of stress concentrations on material properties at elevated temperatures. Included in this program are various design studies of turbine-blade fastenings for both brittle and ductile materials.

The object of this program is to supply data which will enable a turbojet engine designer to reduce the critical element content of a given engine and achieve economical designs. Analytical studies are made of the stress distribution in both blades and rotor disks with a view to providing the most rational design methods for these components. Blade vibration problems are investigated both in the laboratory and in the operating engine.

The results of such studies are analyzed to provide information which would indicate the best manner of achieving reduction in vibratory stress magnitude by control of the exciting forces or by introduction of damping into the system.

Very extensive facilities are available for this type of work. Included are approximately 50 stress-rupture machines, photoelastic equipment, four tensile machines, a number of spin pits including two large enough to burst full-scale turbine wheels under operating temperature conditions, a large amount of vibration-measuring equipment for use at elevated temperatures, and an electronic differential analyzer. In addition, the research group utilizes full-scale engine-testing facilities as required.

The Lewis Laboratory also is conducting research in physics of solids, particularly with respect to strength of materials at high temperatures. Among typical problems in metallurgical physics under investigation are sintering of powders, studies of creep and tensile strength, and studies of embrittlement of high-temperature materials by impurities.

Theoretical work in physical chemistry is mainly in the fields of chemical thermodynamics and kinetics of systems containing solids. Examples of experimental problems are: A study of the effect of surface composition on the creep rate of single crystals of materials, and determination of the vapor pressures of certain intermetallic compounds and alloys.

JET ENGINE COMPRESSORS

The compressor in the jet engine takes in a large quantity of air, compresses it efficiently, and delivers it at a high pressure to the combustion chamber. Each of several types of compressors - axial flow, mixed flow, centrifugal flow, etc. - has certain inherent advantages that may be exploited in specific engine designs.

The rapid increase in the thrust of the turbojet engine has required corresponding increase in capacity, pressure ratio, efficiency, and reliability of the compressor. The turbojet engine development of the past 10 years has required that the power absorbed by the compressor increase from 3,000 to 30,000 hp. Compressors - either single or multiple spool - absorbing even more power are envisioned for future aircraft jet engines.

At the Lewis Flight Propulsion Laboratory, research on jet-engine compressors is directed toward the development of compact, light, efficient machines having high pressure ratio per unit length, and maximum air flow per unit of frontal area. Theoretical studies are made of the basic aerodynamic phenomena connected with the compression of the air as it moves through the compressor. Experimental evaluations of compressors are made to develop design techniques for industry.

The problem of compressor surge is studied to determine its cause and to define the compressor parameters that can be altered to permit operating the compressor over a wider range without surging. The

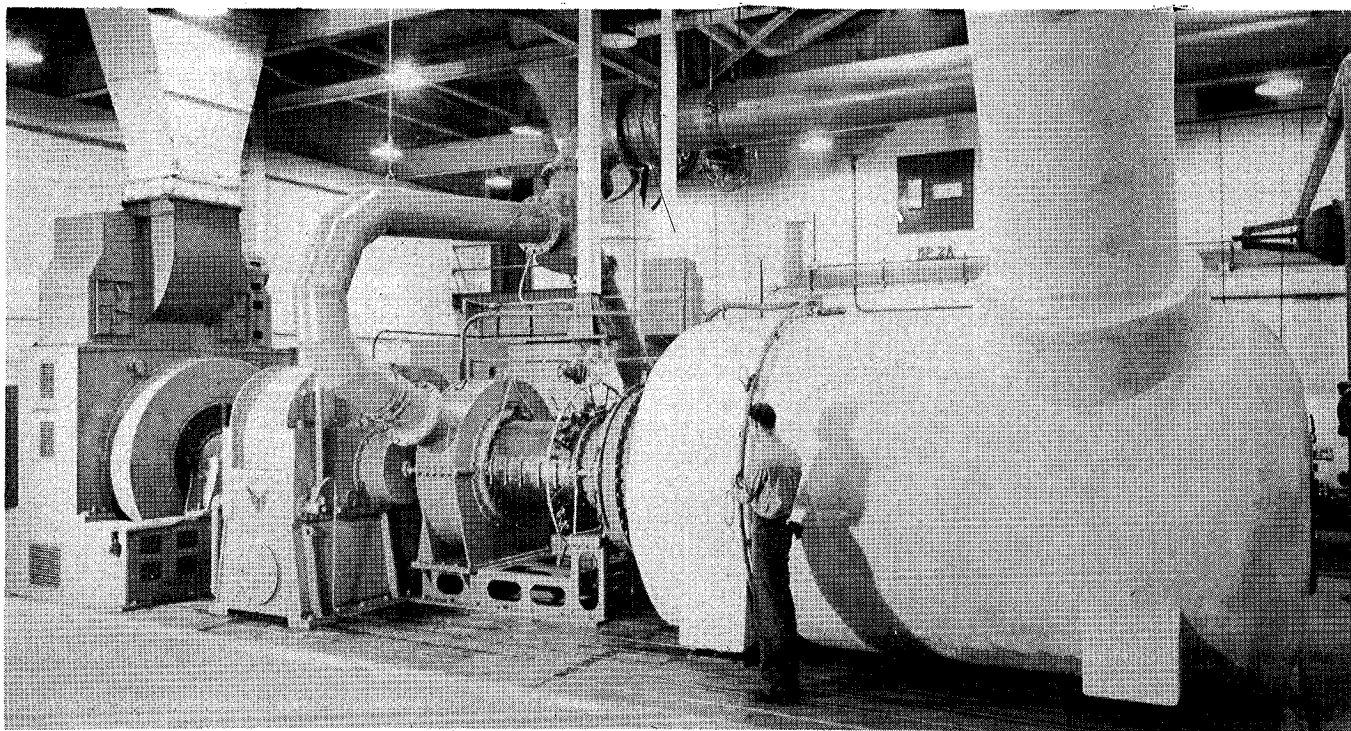
improvement of the axial-flow compressor efficiency at part speed and the effect of this improvement on the surge characteristics is an active research problem. The investigations of surge limitation, stage matching, and off-design performance in high-pressure-ratio multistage axial-flow compressors are conducted on both experimental and commercial prototype compressors.

A research team conducts theoretical analysis and experimental testing of the impeller and diffuser of centrifugal compressors to establish the merits of the theoretical results. Analytical studies of impellers are made in which flow variations from tip to shroud and from blade to blade are investigated.

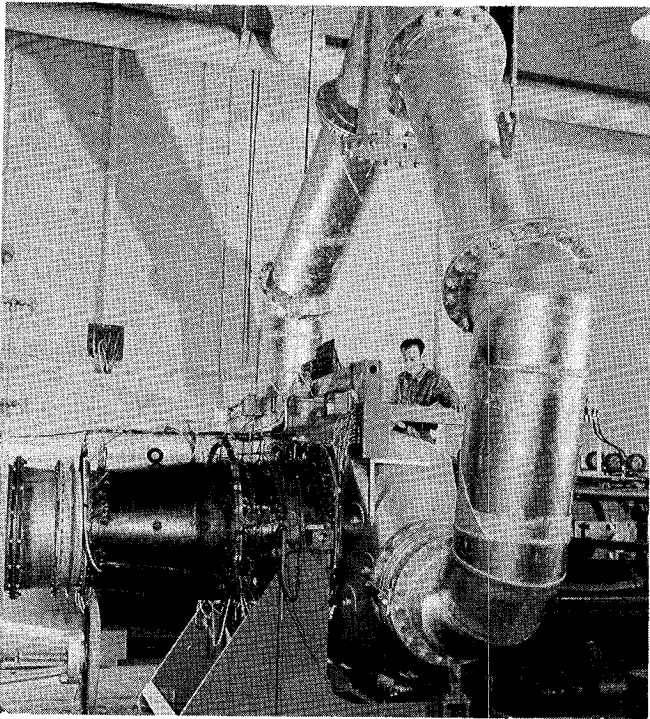
A solution of the design problems of advanced compressor types is of extreme importance for future high-performance jet engines because these new compressor types have large air-handling capacity per unit of frontal area and high pressure ratio per stage.

The mechanical problems of performing research on the flow characteristics of high-tip-speed supersonic impellers are reduced by driving the experimental impeller in a closed system using freon gas at half the rotative speed required for air operation.

Compressor research at the Lewis Laboratory is conducted in the Compressor and Turbine Wing of the Engine Research Building. Electric dynamometers ranging from 1,500 to 15,000 hp with variable-frequency speed control are provided for the driving of compressors in ten large test setups. The central air supply and refrigerating systems that serve the combustion and altitude research facilities are also used for compressor research.



TEST RIG FOR JET ENGINE COMPRESSORS AT LEWIS LABORATORY



APPARATUS FOR TESTING TURBINES

The general requirements of the turbine for the compressor-turbine engine are that it must be small in over-all diameter, light, and as an engine component it must match the performance of the compressor. The severe aerodynamic demands must be balanced against the limitations of material stress at elevated temperatures.

At the Lewis Laboratory, large production turbines from commercial turbojet engines are operated at altitude conditions to determine their over-all performance, sources of losses, and maximum characteristics of the compressor they drive.

The gas turbine for the turboprop engine must drive not only the air compressor but the propeller. This requires the use of additional gas turbine stages and imposes a more complex turbine design problem.

The problem of increasing turbine efficiency is an important one, since improvements have the direct effect of increasing engine efficiency. The most promising areas for research leading to future increases in turbine efficiency are in aerodynamic and thermodynamic improvements.

A more detailed knowledge of the actual flow conditions through the turbine, an aerodynamic problem, is necessary to establish improved design methods. In addition, it is necessary that design principles and theory be developed to the point where the turbine performance can be predicted accurately.

Theoretical and experimental studies are therefore in progress at Lewis to obtain basic aerodynamic information on the flow through turbine cascades. Aside from the study directed toward the flow through a single stage, considerable effort is being expended on the equally important problem of determining the interaction of successive stages.

GAS TURBINES

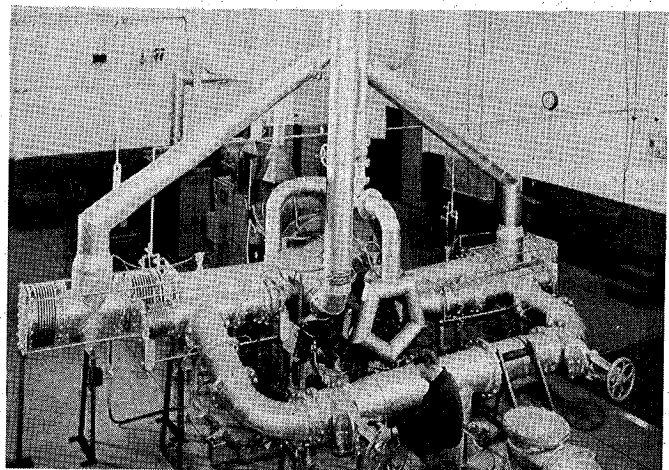
For many applications of gas-turbine engines, it is advantageous to increase the turbine inlet gas temperature in order to increase the power output of the engine. Two methods are available that will permit the turbine to operate satisfactorily at increased gas temperature levels: (1) development of materials which will withstand operation at increased temperatures, and (2) development of means for cooling the turbine blades so that present blade materials can be used even though the gas temperature is increased.

In addition to finding methods for permitting increased gas temperatures, turbine cooling research is also directed toward reducing the turbine material temperature to a point that plentiful, low-alloy steels may be substituted for the scarce, high-temperature materials now in use.

Turbine cooling studies are conducted on full-scale turbojet engines that have been redesigned to accommodate cooling. Endurance investigations are conducted to determine the structural durability of various cooling designs, and performance investigations are conducted to determine the effects of cooling on the over-all engine performance.

Successful application of new-type intermetallic low-ductility material for turbine blades requires the study of the heat-shock resistant properties of hot-pressed blades under centrifugal loads and high gas temperatures. Cermets and intermetallic materials are studied to determine methods of production of the complex shapes needed for turbine blading. A method of attaching these brittle blades to the turbine disk so as to prevent the failure of the blade in the root is a major research problem.

Turbine aerodynamic research is performed at Lewis in the Engine Research Building, where large air compressors, hot gas generators, exhaust gas coolers, and exhaust pumps make it possible to duplicate any conditions encountered in flight up to an altitude of 60,000 feet. Turbine material and cooling studies are conducted in numerous sea-level test stands in full-scale engines.



EQUIPMENT USED IN TURBINE RESEARCH

RAM-JET AND ROCKET ENGINES

Ram-jet engines are inherently suitable for supersonic flight because of their ability to handle large quantities of air relative to their size and because their power increases with flight speed. Some form of booster rocket is required to accelerate the ram jet to operating speeds.

The problem of designing efficient inlets for ram jets operating at supersonic speeds is made difficult by the sensitivity of the inlets at supersonic speeds to operation at altitudes and speeds other than those for which the engine is designed. Research at Lewis Laboratory is directed to evaluating the off-design characteristics of various types of supersonic inlets in different locations on the aircraft to determine how they influence the utility of ram-jet engines of a fixed design during maneuvering conditions.

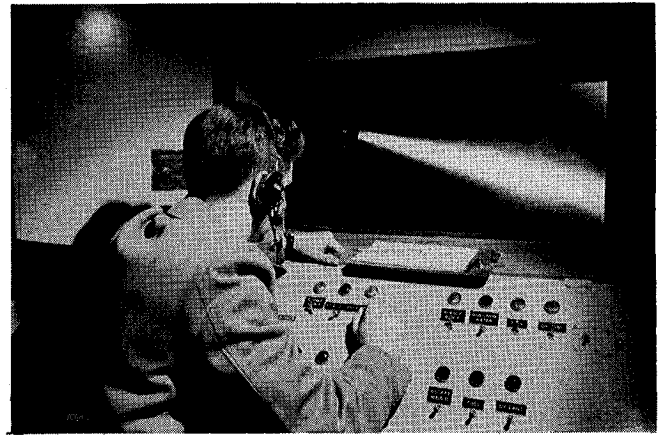
Under certain operating conditions, the combustion in the ram-jet engine may pulsate with a serious loss in ram compression. The flow pulsations are caused by inlet diffuser and combustor phenomena.

Since air in the ram-jet engine passes through the combustion chamber at high speed, there is a tendency for the flame to blow out. Operating the engine at altitude with resulting low pressure also makes the attainment of efficient combustion difficult.

The utilization of special high-energy fuels in the ram jet offers gains in thrust, range, or operating limits, but at the same time presents rather imposing combustion-equipment problems. Among these are exceptionally high temperatures which destroy combustion chambers, and solid deposits which build up on flame holders, walls, and exit nozzles.



TESTING PRESSURE TAPS ON RAM-JET SPIKE



TEST OF ROCKET COMBUSTION

The 8 x 6-Foot Supersonic Wind Tunnel at Lewis and several smaller supersonic tunnels can be used for studying both the aerodynamic and combustion problems of model ram-jet engines. The large tunnel can be operated over a range of Mach numbers from 1.4 to 2.0, and the smaller tunnels to over 3.0.

The altitude chambers available in the Engine Research Building and the Propulsion Systems Laboratory can be used for studying combustion in full-scale ram jets up to 60 inches in diameter.

The research facilities at Lewis permit the investigation of ram-jet engine problems over a wide range of inlet temperatures, altitudes, and air speeds.

ROCKET ENGINES. The rocket engine develops the greatest thrust per unit of engine weight with the smallest frontal area per pound of thrust of all engines used in aircraft propulsion. Its performance is independent of altitude because it carries its own oxidant and does not depend upon the earth's atmosphere. The Lewis Laboratory's research is directed toward investigations of combustion, ignition, and cooling.

Reliable low-temperature starts are required of air-to-air and air-to-surface rocket missiles and booster jet engines when used under high-altitude conditions. Search for fuel-oxidant combinations that are self-igniting at low temperatures is a research problem. The characteristics of high-specific-impulse propellants are studied in special research rockets.

A cyclical low-frequency type of instability characterized by fluctuation in chamber pressure and nozzle flow or thrust in a certain frequency range is called "chugging." This type of instability may change performance or cause rapid failure from overheating or stress fatigue.

An analytical investigation of internal liquid-film cooling of rockets is being correlated with experimental data that will permit the prediction of film-coolant requirements. The coolant may be injected uniformly about the circumference of the nozzle entrance or through porous walls of the combustion chamber.

Rocket research is conducted in a battery of 14 individual test stands having centrally-located banks of fast recording instruments that can be connected to the various test cells. Operation is observed by means of periscope, television, or movie cameras.

The proof of the correctness of the research data, and of how well the technical information available from the research studies of the jet-engine components has been incorporated in the jet-engine design, can be obtained only by an evaluation of the complete engine.

The matching of the compressor and turbine, the combustion characteristics of the main engine and afterburner, the response of the engine to its controls, the measurement of air flow losses, fuel consumption, and thrust of the engine are all obtained from studies of the complete engine. The effects of altitude, flight Mach number, and inlet air temperature on the radial distribution of turbine outlet gas temperature, and the effect of these same parameters on the regions of compressor surge, are typical problems investigated on the complete engine.

A host of new aerodynamic, thermodynamic, vibration, materials, and operating problems arises when the individual components are assembled in the complete engine. These problems must be solved before the developed engine can be specified as a propulsion unit for high-altitude, high-performance military aircraft.

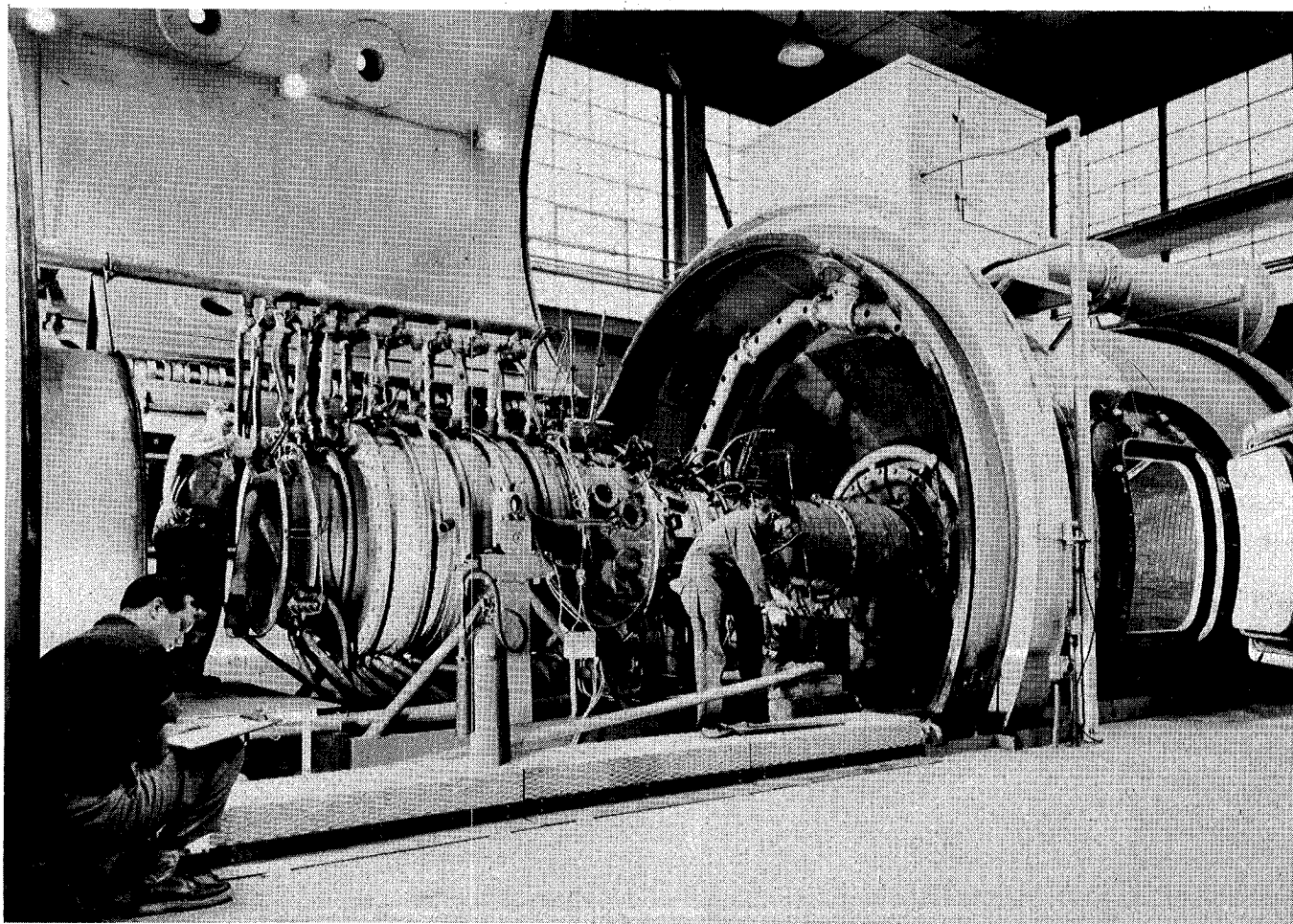
Combined compressor coolant injection and tail-pipe burning as a means of turbojet-engine thrust

JET ENGINE OPERATING CHARACTERISTICS

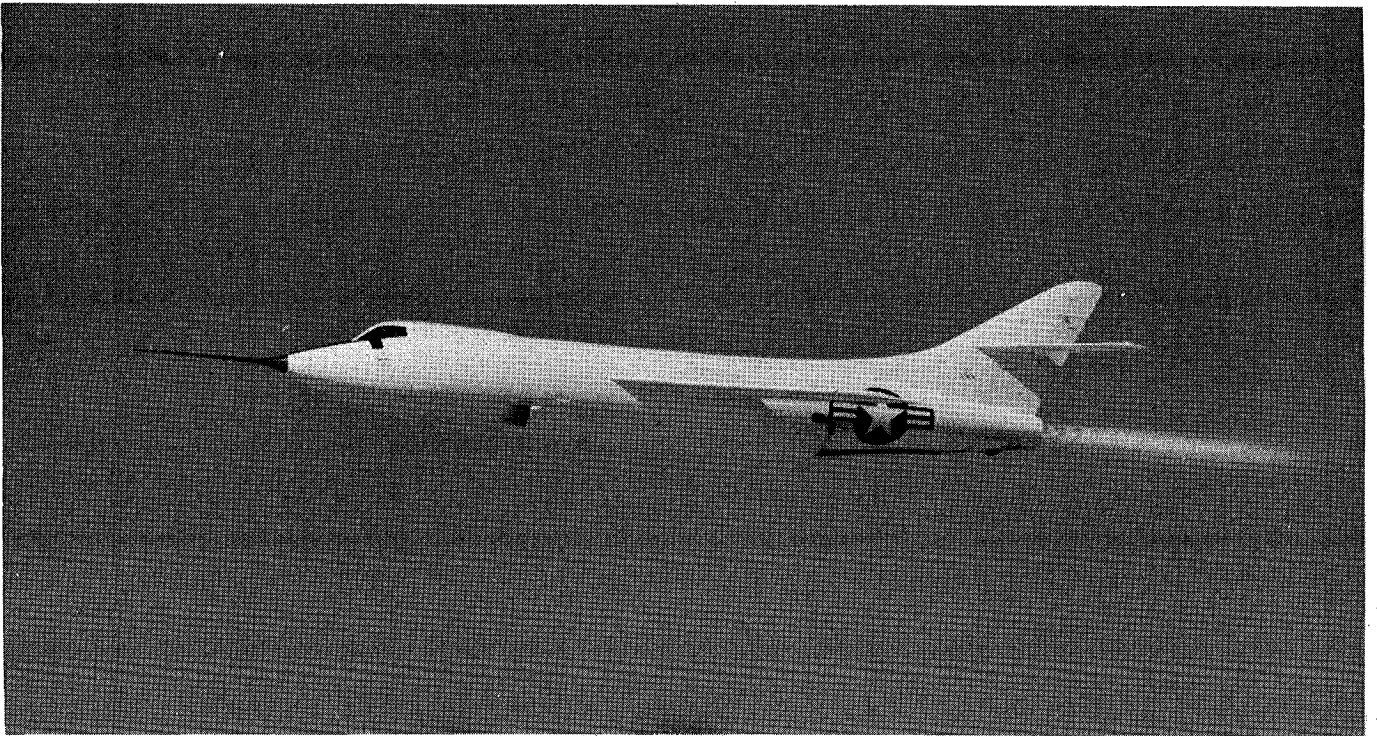
augmentation for take-off and for certain flight maneuvers are studied at Lewis on full-scale engines in the Jet Propulsion Static Laboratory and in the Engine Research Building.

Analytical studies are made to determine the effect of various flight paths, Mach numbers, and configurations on the choice of optimum turbojet-engine design for the propulsion of supersonic interceptors and bomber-type airplanes. Such factors as compression pressure ratio, compressor efficiency, turbine inlet temperature, afterburner injection, air flow capacity, and engine weight are evaluated in the analysis.

The Lewis Laboratory has the necessary research equipment to evaluate all current full-scale turbojet, turboprop, and ram-jet engines. The 20-Foot Altitude Wind Tunnel, the two 10-foot-diameter altitude chambers in the Engine Research Building, and the two 14-foot-diameter altitude chambers in the Propulsion Systems Laboratory can be operated over a wide range of inlet air temperatures, altitudes, and inlet air Mach numbers.



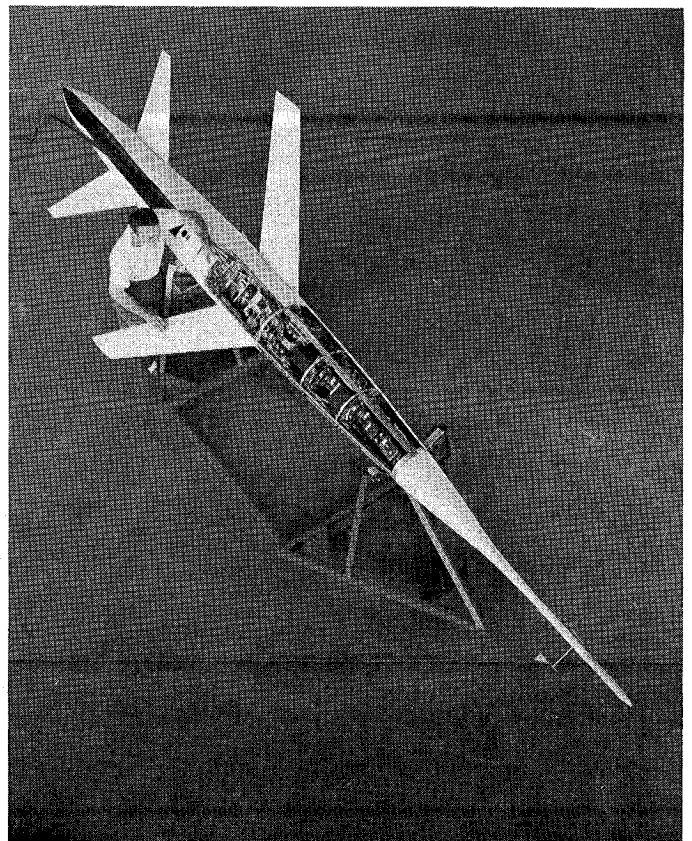
LARGEST JET ENGINES CAN BE TESTED AT FULL POWER IN THIS ALTITUDE TANK



D-558-II ON RESEARCH FLIGHT



INSTRUMENTING FIGHTER FOR RESEARCH FLIGHT



DROP-TEST MODEL WITH INSTRUMENTATION

FLIGHT RESEARCH

When NACA began research operations in a small way in 1917, two Jenny biplanes loaned by the Army Signal Corps became the NACA's first research facilities. Aerodynamic problems were studied in flight. NACA had no wind tunnels.

As wind tunnels and other facilities were built, the scope of flight research was also expanded. Today, the Langley, Ames, and Lewis Laboratories each have a Flight Research Division which operates as an integral and indispensable member of the aeronautical research team.

Basically, the function of these flight research groups is to conduct tests on full-scale airplanes under conditions of speed, altitude, acceleration and power not capable of simultaneous duplication in wind tunnels. At Langley and Ames, flight research deals primarily with aerodynamics; at Lewis, it is devoted to propulsion and operating problems.

Generally speaking, aerodynamic research by means of flight tests falls into the two broad categories of air loads and dynamics.

With respect to air loads, first there are tests to measure the loads imposed on the airplane resulting from manipulation of the controls during maneuvers. Second, there are tests to measure loads imposed on the structure in flying through turbulent air. Third, there are fatigue tests to determine the "life" of a structure.

With respect to dynamics, the responses of airplanes are investigated to determine stability and control characteristics which permit the airplane to be flown with ease, precision and safety. Research in this category is intended to supply information for formulating design specifications for the configuration and control systems of various classes of airplanes.

As ever higher speeds and altitudes are attained, stability and control problems have become greatly aggravated. Extensive flight research has been conducted to study the tracking performance of jet fighters, with the goal of making them steadier gun platforms.

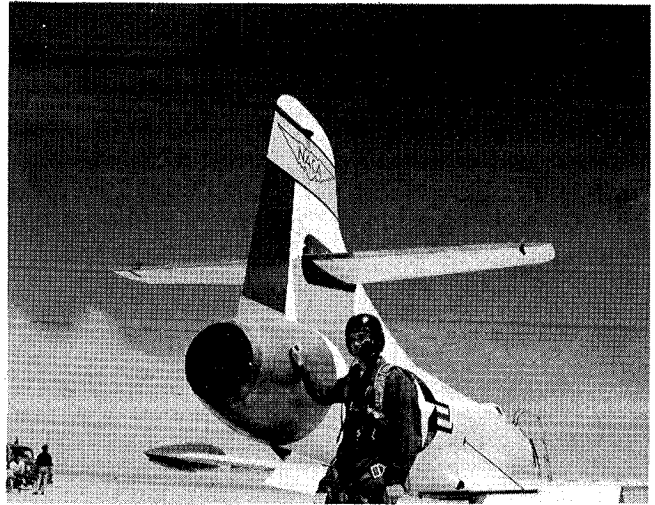
Flutter, a vibration of some part of an airplane excited by the imposition of air loads, is another problem under constant study. It has become more serious and complex in jet planes which fly close to the speed of sound and maneuver at very high altitudes, since such planes have thin and relatively flexible wings.

In the Aircraft Loads Calibration Laboratory, airplanes which have been instrumented in preparation for flight loads research can be subjected to measured loads, and the known loads are then correlated with readings given by the instruments. This insures that the loads measured later, during actual flight, can be known exactly. Fatigue tests, in which an actual airplane wing is flexed continuously until it fails, also are conducted in the Loads Calibration Laboratory.

Flight research in both air loads and dynamics is applied to all types of aircraft - fighters, bombers, transports, helicopters and personal. Except for the private-owner class, airplanes tested by the NACA are provided by the military services.

All the NACA research pilots are graduate engineers or scientists as well as highly-trained fliers, for the work involved must be thoroughly understood and executed with precision.

The NACA pilots fly new planes not primarily to



PILOT NEEDS SCIENCE OR ENGINEERING DEGREE

test these particular models, but to study fundamental problems that might apply to other airplanes of similar design. In all of these tests, specially-designed measuring and recording instruments are installed in the airplane to measure the various quantities pertinent to the problem being investigated, such as speed, altitude, acceleration, attitudes, and strain.

Flight research provides the final check on any theoretical or wind tunnel findings, and extends the usefulness of wind-tunnel research by serving as a measure of verification or correction for wind-tunnel data. Conversely, wind-tunnel research provides a valuable guide in planning and interpreting flight tests.



TEST DEVICES ON HELICOPTER

RESEARCH AIRPLANES

Toward the end of World War II, the advent of turbojet and rocket engines made urgent the need for information about the transonic speed zone, where air flow is a confusing, unpredictable mixture of subsonic and supersonic flows. In planning intensive exploration of this speed range, the Air Force, Navy, aircraft manufacturers, and the NACA joined forces.

Because the necessary information could not be obtained in the laboratory - transonic wind tunnels had not been developed then - it was decided that full-size, specially-designed, piloted airplanes would be used. These were to be equipped with instruments to measure the desired data.

The daring program agreed upon called for the construction of a series of high-speed airplanes to penetrate the transonic or low supersonic speed ranges. The planes were constructed by four different manufacturers under Air Force or Navy contracts, designers leaning heavily upon data obtained in NACA wind tunnels and, later, in pilotless aircraft research at Wallops Island.

First to be completed and flown was the Bell X-1, a small stubby-winged rocket plane which pierced the so-called "sonic barrier" on October 14, 1947.

Meanwhile, NACA established its High-Speed Flight Research Station at Muroc, California, which is now called Edwards. At this vast desert air base, home of the Air Force Flight Test Center, the research airplane projects are conducted as a cooperative venture by NACA, the military services, and the aircraft industry. At least eight different research airplanes have been built, plus a number of duplicates.

All these custom-built, highly-instrumented research vehicles were designed for the investigation of airplane configurations that promised certain advantages for high-speed flight. Most were intended for transonic studies, some for supersonic. A variety of wing shapes explored the possibilities of straight, swept, movable, and triangular wings. The power plants are of turbojet, turbojet with afterburner, or rocket type.



GROUND RADAR CHECKS FLIGHTS

In August 1951, only four years after supersonic flight was proved possible, the rocket-powered Douglas D-558-2 Skyrocket was clocked at 1,238 mph at an altitude of 79,494 feet.

Several very fast military planes designed for tactical use also are involved in the NACA projects at Edwards.

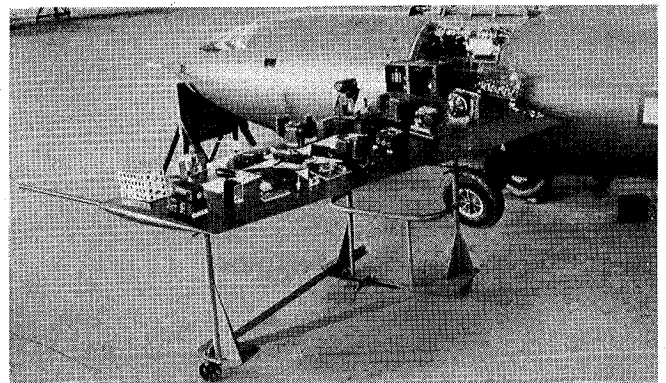
One aim of the program is to study the behavior of aircraft at transonic and supersonic speeds, in order to establish operational standards for future high-speed military planes. The investigation of stability and control, both by means of recording instruments and pilot's opinion, is a major subject in connection with each of the research airplanes.

Air loads imposed on the wings, tail, and fuselage during maneuvers are another subject of prime importance. These loads are measured by scores of resistance wire strain gages and air pressure pickups placed at strategic points, principally on the wings and tail. The strain gages measure the total aerodynamic load and show its approximate center, while the pressure pickups plot a more detailed pattern of pressure distribution.

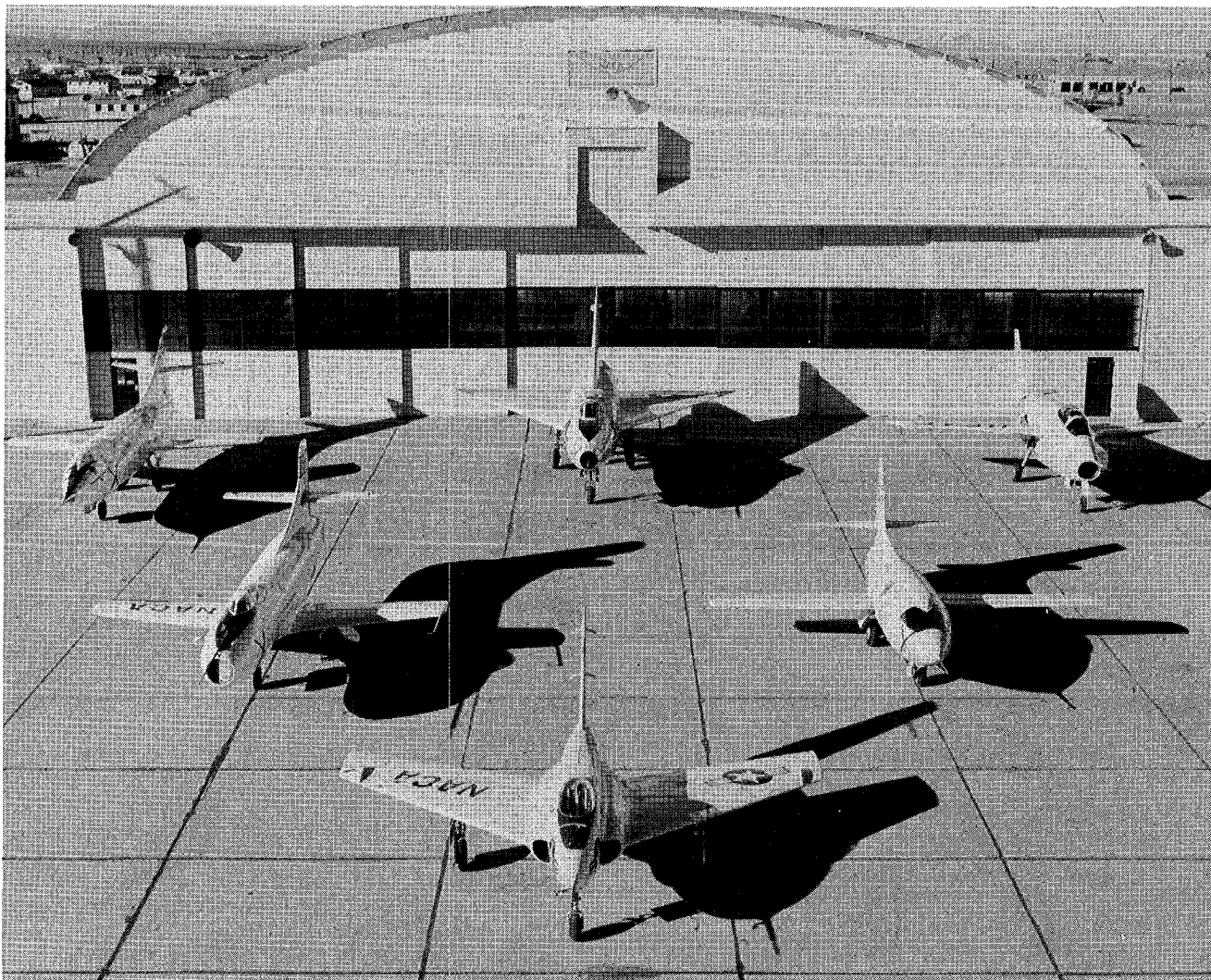
In a typical test, the research airplane may be provided with 100 to 200 strain gages and about 400 pressure orifices. During maneuvers, measurements are recorded by automatic equipment. Even though compact, lightweight instruments are used, the instrumentation and wiring installed in a research airplane often weigh 500 pounds or more.

Speed, rate of climb, drag, and other performance features of the research airplanes are determined at transonic and supersonic speeds and during maneuvering flight. The research flights are building up a mass of detailed technical information on aerodynamic loads and performance. Difficulties in instrumenting the airplane impose some limitations, but the data obtained by flying an actual airplane offer some advantages over data obtained in wind tunnels.

The test results can be applied directly to full-scale aircraft. Certain corrections necessary with wind tunnel models, particularly models of smaller scale, are not required. Loads can be measured under a wide range of maneuvering conditions. The pilot can feel control forces and form an opinion of the plane's handling qualities. In addition, there is always the possibility that an actual flight may call attention to



DISPLAY OF X-1's RESEARCH INSTRUMENTS



NACA's RESEARCH AIRPLANES: D-558-II, D-558-I, X-4, XF-92A (REAR), X-1, X-5

some unusual dynamic behavior that has not been anticipated.

NACA pilots share the research airplanes with test pilots of the Air Force, Navy, and manufacturers concerned. During every research flight, one or two fast military planes are assigned as "chase" airplanes to watch for trouble such as improper firing of the rocket engine, and to assist the research pilot in making a "hot" landing with limited visibility. The pilots talk with each other and with ground observers by radio. The chase airplanes are part of the methodical, thorough planning which reduces the calculated risk inherent in flying supersonic airplanes.

To conserve their fuel supply, which lasts only a few minutes, the two rocket planes that have flown faster than sound - the X-1 and the Skyrocket - are carried aloft beneath a "mother plane" and launched at a height of about 30,000 feet.

Except for the delta-wing XF-92A, which was designed as an experimental jet fighter, the research airplanes used at Edwards are not prototypes of military planes, although it is likely many of their design

features will be copied.

The research airplane projects are closely linked with flight research conducted at Ames and Langley, with pilotless aircraft research at Wallops Island, and with studies carried on in high-speed wind tunnels. The various phases of aerodynamic investigation supplement and confirm each other.

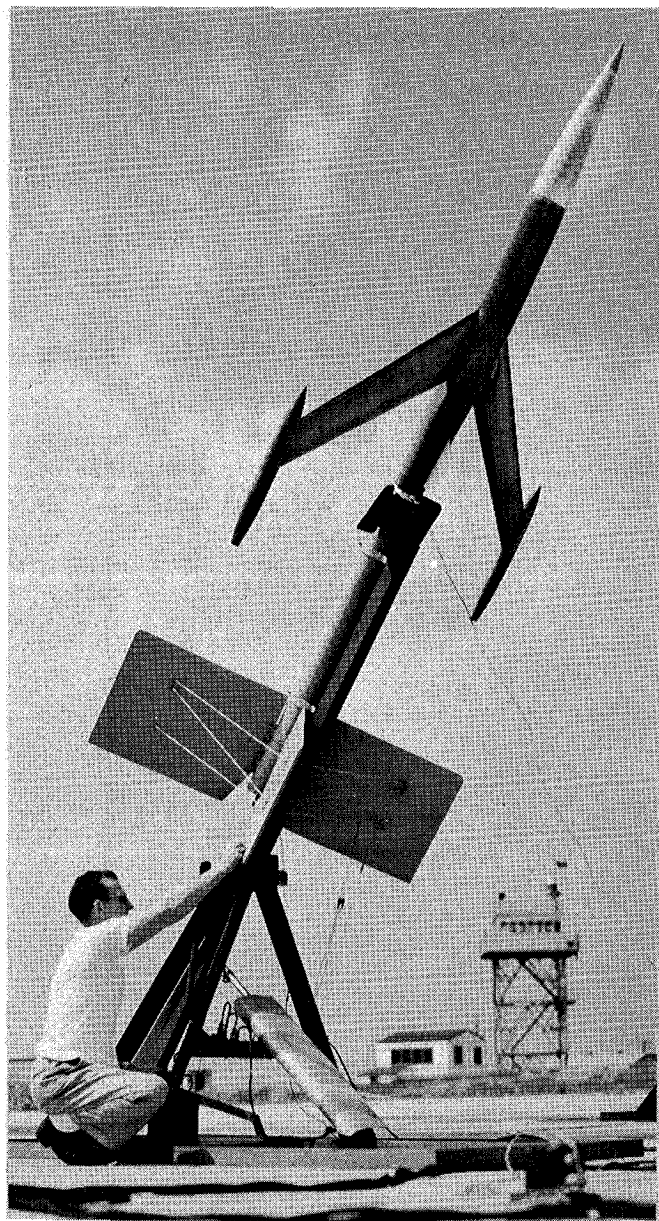
In the laboratory, conditions can be isolated and studied with a precision which is extremely valuable. But it is only in flight itself that the problems can be studied as a whole. Not only that, but problems related to loads, dynamics, and operation can best be attacked by flight tests on full-scale airplanes.

Tomorrow's tactical airplanes, the ones now being readied for the flight lines and still on the drafting boards, will reflect in many ways new aerodynamic knowledge gained from the program. At the same time, the research pilots of the NACA continue to make good use of these special airplanes, developing additional information which will be similarly valuable to the nation's aircraft industry.

PILOTLESS AIRCRAFT

During World War II, NACA scientists saw the possibility of using rocket-propelled research models to obtain aerodynamic information in the transonic and supersonic speed ranges. To take advantage of this radical new method, it was necessary to build the Pilotless Aircraft Research Station on Wallops Island, Virginia, which began operations in July 1945.

This isolated station on the Atlantic seacoast, operated by the Pilotless Aircraft Research Division of Langley Laboratory, is a firing range for rocket-powered, free-flying, highly instrumented models designed and constructed at the laboratory. Propelled by high-velocity rockets such as fighter planes fire



RESEARCH MODEL ON LAUNCHER

against ground targets, the research models are launched from the beach at terrific speeds to provide new data on wing lift, drag, dynamic stability, control effectiveness, buffeting, flutter, aeroelasticity, boundary layer, aerodynamic heating, and ram-jet engine performance.

Some research models fly three or even four times as fast as the speed of sound, which means they have been clocked in the neighborhood of 3,000 miles per hour. Most models attain a top speed around 1,200 mph and an altitude between 15,000 and 30,000 feet.

During the model's brief flight of a minute or two, automatic instruments record its velocity, drag, stability characteristics, and other information sought. Movie cameras track the model and radar follows it beyond the limits of sight. Tiny instruments carried inside the model send a continuous record of air pressures, acceleration, control positions, angle of attack, and other data to the ground station by radio.

Sometimes a dynamic scale model of a proposed military airplane is tested at Wallops while the plane is still in the design stage. The flight test of such a rocket-powered model may disclose ways to improve materially performance and safety before the full-scale airplane is built. For example, the tail design may be modified, resulting in better stability and control. Such changes can make the pilot's first flight safer and perhaps prevent destruction of a million-dollar prototype.

The flight test of a scale model also reveals, from a study of measured drag values, whether the airplane will be able to attain its expected top speed in flight. If not, the NACA scientists may recommend design changes and then fly another model that has been modified to reduce drag. This preliminary test aids the manufacturer and military services to realize their original speed goal.

Most of the research models flown at Wallops, however, do not represent any specific airplane; they are merely "aerodynamic shapes," sometimes of quite unconventional design. The NACA's research with pilotless aircraft runs about five years ahead of production airplanes, providing aerodynamic data needed by the designers of tomorrow's ultrafast jet fighters, high-speed bombers, and guided missiles.

The data obtained by using free-flying models is closely related to that gained in flight research and in high-speed wind tunnels. NACA's research with pilotless aircraft, in fact, might be considered an extension of the wind tunnel studies to higher speeds and larger scale, or Reynolds number.

Because they are large and fly very fast through relatively dense air, the rocket-propelled models yield full-scale aerodynamic results. In flight, they approximate the conditions that would be encountered by a full-size fighter airplane at its normal operating altitude.

Much of the research information learned at Wallops can be applied to both high-speed airplanes and missiles. The missile problems studied there usually relate to the improvement of stability and control or performance. In the case of newly-designed airplanes, Wallops might be described as an intermediate step between the wind tunnel studies and the first flight test at Edwards Air Force Base.

The quality of aeronautical research depends upon precise measurements. Good instrumentation, therefore, is essential to its success.

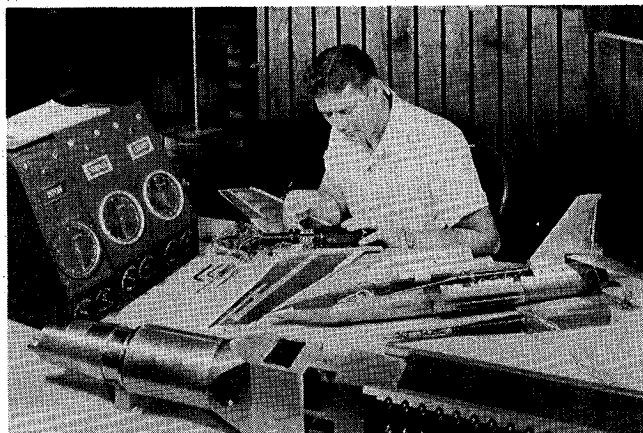
As wind tunnels grew larger and faster, and as more complicated methods came into use in flight research, structures research, and all types of NACA investigations, it became necessary to improve or invent instruments capable of recording the test results. Instrument research and development was forced to keep pace with advances made by the aerodynamicist, and these advances demanded extreme accuracy and reliability under adverse conditions of temperature, pressure, and acceleration.

Devices available on the commercial market are used whenever possible. Frequently, they are modified by NACA to serve some new purpose. But most commercial instruments are not suitable for the specialized work required.

For example, the pickups (sensing devices) and telemeter (radio transmitter) installed in a rocket-propelled flying model must be extremely small and light, yet rugged enough to withstand the firing acceleration of 30 g's or more. An over-all accuracy of 96 to 100 percent is demanded.

Research with pilotless aircraft is entirely dependent upon adequate instrumentation for tracking the models, for measuring velocity, acceleration, air pressure, strain, and other conditions in flight, and for recording the flight data automatically and instantaneously. Neither these studies nor the full-scale investigations conducted with piloted research airplanes at Edwards would be possible if hundreds of remarkable miniature instruments had not been designed and developed by

INSTRUMENTATION



INSTRUMENTING A WIND-TUNNEL MODEL

NACA especially for the purpose.

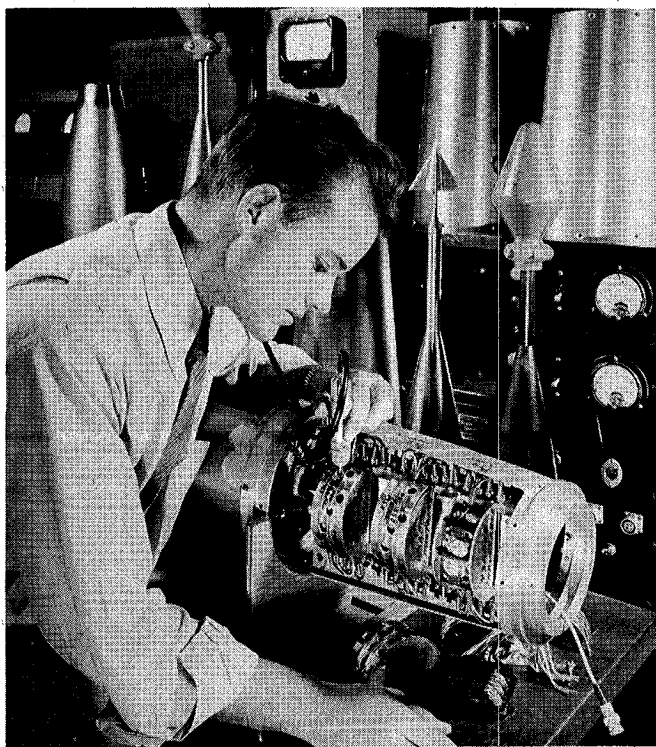
The velocity-gravity recorder, accelerometer, a tiny cell for measuring air pressure, and several types of photographic recording devices are examples of the many small, specialized instruments designed or developed by NACA scientists.

Most of the instruments are designed to make a rapid, automatic record of experimental test data. When a large model is used in a wind tunnel, there may be as many as 300 points at which pressure is measured simultaneously, by means of tiny pressure orifices, and recorded by photographing a manometer board. At Wallops, 10 "channels" of test data can be radioed simultaneously and continuously from a flying model. On the ground, the radio signals are recorded as a long, continuous-line graph.

At Langley Laboratory, the Instrument Research Division is charged with responsibility for providing the instrumentation used in wind tunnels, flight research, structures and loads work, and pilotless aircraft. It also provides most of the instrumentation for the research airplanes at Edwards. The Ames and Lewis Laboratories have similar, though smaller, instrument services.

Growing rapidly as a result of the increasing complexity of aeronautical research, the Instrument Research Division occupies a large building honeycombed with workshops, laboratories and offices. Here a staff of electrical engineers, electronics specialists, physicists and mechanical engineers, working with instrument technicians, has developed and constructed thousands of electrical, mechanical, optical, and electronic instruments vital to the success of NACA research. The calibration, servicing, and repair of instruments also is handled by this division.

One branch of the division supplies instrumentation for ground facilities such as the wind tunnels, towing tanks, impact basin, and helicopter tower; another solves instrumentation problems in the airplanes used in flight research at Langley and Edwards, and the third handles the instrumentation used in rocket-powered models fired at Wallops Island. This includes telemetering and radar work.



ELECTRONICS SPECIALIST AT WORK

OPERATING PROBLEMS



TEST SET-UP IN THE ICE TUNNEL

Airplanes of every type are subject to operating hazards such as fires in flight, icing, forced landings, severe gusts, and poor visibility. Since any of these adverse conditions could cause a fatal crash, reduction of the hazards is of vital concern to commercial airlines and the military services.

The NACA maintains a Committee on Operating Problems, and all three laboratories participate in research aimed at reducing such dangers.

The prevention of fire in airplanes after survivable crash landings has been actively studied at the Lewis Flight Propulsion Laboratory. Service-weary cargo planes, provided by the Air Force, have been thoroughly instrumented to measure temperature, combustible vapors, decelerations, fuel-line failures, and short circuits or arcs. Then the planes were crashed so as to simulate a takeoff accident in order to gain precise knowledge about how aircraft fires were started and how they spread.

Methods for preventing the formation of ice on the leading edges of wings, tail, and propellers have been studied by the Lewis Laboratory for many years. One wind tunnel there produces freezing rain to simulate any degree of icing conditions at air speeds up to 435 mph. Many tests were conducted by flying an airplane under natural icing conditions.

The thermal ice prevention system developed by NACA is now standard equipment for fast military planes and for most transport and cargo planes.

Icing is still a severe problem for jet engines, which suck in enormous amounts of air and moisture. Axial flow units are particularly vulnerable.

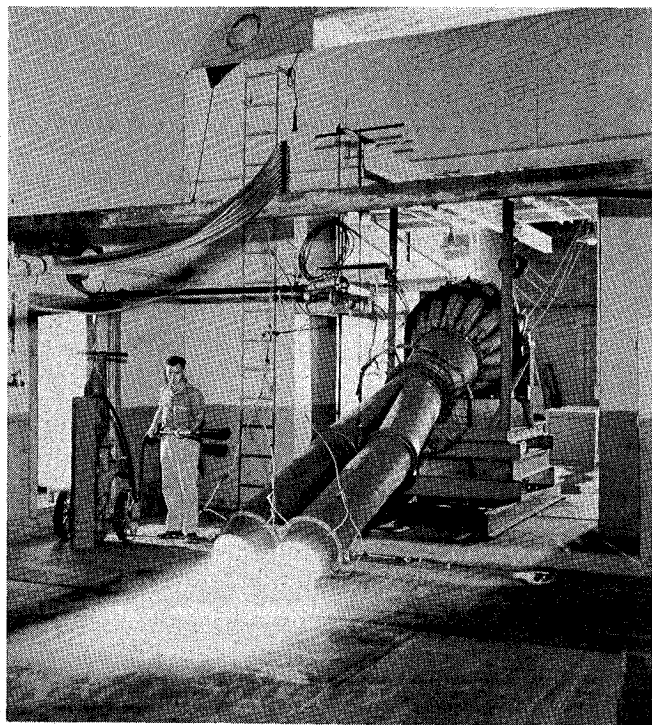
Crash landings, particularly the "ditching" of landplanes in water, have received considerable attention from NACA scientists. Experimenting with models the Hydrodynamics Division at Langley has compiled information to help aircraft manufacturers design planes with better ditching characteristics. The ditching studies have proved useful to pilots, too.

Air gusts encountered at high altitude, in clear air have been studied over a long period by the NACA in cooperation with the commercial airlines, military services, and the U. S. Weather Bureau. Thousands of airline transports, on their regular runs, carry an automatic device that records the severity and frequency of gusts encountered above 10,000 feet, and military pilots furnish similar reports above 25,000 feet. These records are analyzed by NACA in an effort to develop methods of predicting high-altitude turbulence. This study may result in a smoother ride for airline passengers and less danger from gusts for military planes.

The Weather Bureau, Air Force, and Navy also cooperate with NACA in studies of thunderstorm turbulence, hurricanes, icing, and other meteorological problems. The use of radar by pilots to detect storms in their path is a current subject of investigation.

Loud noise caused by airplanes, a subject of frequent complaints from those who live near airports, also gets attention from NACA. Causes of the noise, and possible methods of noise reduction, are being studied. Inadvertent speed increases in transport operation, which might cause a plane to exceed placard speed in prolonged descents, have been investigated.

The Flight Research Divisions of all three laboratories and the Dynamic Loads Division at Langley handle most of the research on operating problems.



CARRIER DECK FLAME TEST

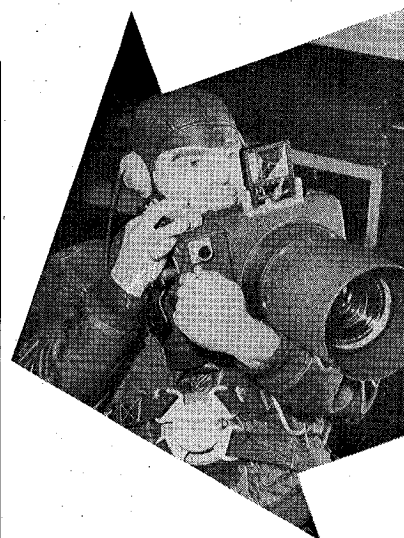


SIMULATING TAKEOFF CRASH. WAR-WEARY PLANE, LOADED WITH INSTRUMENTS, NEARS BARRIER



DUST AND FUEL MIST CREATE FIRE HAZARDS AS PLANE SKIDS ON GROUND

TEAMWORK



THE RESEARCH TEAM

In NACA there are two major kinds of teamwork - among scientists in different fields and among scientists and supporting personnel.

As illustrated above, NACA scientists frequently get together to exchange ideas and findings and to plan their work.

Typically, a research project is given to a team of scientists representing different backgrounds. For example, a scientist with a college degree in physics may be teamed with others having degrees in mechanical and electrical engineering and in electronics. This brings to bear on the problem a variety of knowledges and skills.

Also, scientists working on different projects often consult because of interrelated problems. The areas of aeronautical research interlock remarkably. For example, problems in aerodynamics often have direct connections not only with such basic fields as mathematical theory, thermodynamics, and research instrumentation, but also with such applied areas as aircraft structures, loads, and propulsion systems.

This constant interchange of ideas, both formal and informal, encourages the "cross fertilization" that often produces brilliant and successful new approaches.

As also illustrated, every NACA scientist has an average of three supporting

personnel for a wide variety of kinds of work.

To be specific, NACA's present approximately 7,500 employees include about 1,900 research scientists and 5,600 others.

Among the 5,600 there are about 550 professional engineers engaged in nonresearch work such as design and modification of research facilities.

About 950 are technical personnel, including computers, draftsmen, illustrators, photographers, engineering and laboratory technicians, and professional librarians and editors.

The largest of all is the group of 3,250 trades-and-crafts and maintenance workers. Most of these are highly skilled model-makers, electronic and mechanical instrument makers, aviation metalsmiths, machinists, aircraft mechanics, electricians, printers, and so on.

The 850 remaining are mostly office employees for clerical, typing, and stenographic work, and specialists in such administrative fields as procurement, accounting, and personnel.



SHOPS AND SERVICES



MAKING A FLYING MODEL FOR SPIN TUNNEL

ENGINEERING. Much of NACA's research equipment has been designed by NACA engineers. The design of new equipment and the modification of existing facilities continually move ahead.

For NACA engineers, unusual and complex problems are the rule rather than the exception.

Very high or very low atmospheric pressures may be required in large volume. Mechanical loads may be quite unusual with respect to required structural conformation. Great quantities of electrical power are consumed, often on an extreme peak-load basis. Interlocking facilities may need special coordinating techniques and devices. There are problems of explosive and poisonous gases, liquids, and solids.

These are only a sample of the challenging problems met and successfully solved by NACA's engineers.

SHOPS. Each of the NACA research centers has large, well-equipped shops where practically every type of woodworking, metalworking, and mechanical operation can be performed. Also included are plastics, optical work, electronics, and so on.

Highly skilled craftsmen do delicate work to extremely close tolerances. Slight irregularities, for example, in the surface of a small airfoil model might produce significant errors in wind tunnel data.

They can make miniature working models of aircraft to be used as "dynamic models," which fly under remote control in the Free-Flight Tunnel, or spin freely in a rising column of air in the Spin Tunnel.

Sheetmetal workers can "spin" sheets of metal into precisely curved aerodynamic shapes for rocket-propelled research models.

Instrument makers construct tiny but complete radio transmitters and measuring instruments, and embed them in plastic, for telemetering information from flying models.

Special machining equipment, some of it developed by NACA, can produce to close tolerances double-curved objects like turbine and compressor blades.

In general, the NACA shops and craftsmen can produce practically any piece of research equipment that the scientist needs. They are accustomed to new and unusual requests. Some NACA craftsmen are inventors in their own right.

PHOTOGRAPHY. There is wide use of photography for recording test data and making record pictures of test setups. Still cameras preserve manometer board readings at the press of a button. Sometimes test results are recorded automatically, in convenient graphic form, on a wide strip film. In other cases, movies make the best record. Special types are also used, such as schlieren photography for air flow, or very-high-speed movie photography for combustion or explosions.

COMPUTERS. The computers, mostly young women, process experimental test data into form suitable for analysis, and perform mathematical and statistical computations. Many are college-trained in higher mathematics.

COMPUTING MACHINES. The NACA has batteries of fast, automatic, high-capacity computing machines of various types. These are used to handle most of the calculations for analytical and certain theoretical work, which are usually very extensive and involved. They are also used for the great mass of data reduction.

One installation, consisting of twin electrical relay digital computers, is a "magic brain" capable of solving long and very complicated problems in a tiny fraction of the time required by a human mathematician. This machine is operated around the clock in an effort to keep pace with research. Mathematical problems are prepared and fed into it in the form of punched tape, with two or three spare problems always in the hopper. Sometimes this automatic computer works continuously, for two or three days and nights, on just one phase of a problem.

LIBRARIES, EDITORS, PRINTERS. To assist in another phase of research work, the NACA has in each laboratory a large technical library, and at Headquarters a much larger one, the Office of Aeronautical Intelligence.

As research is completed, editorial assistants help the scientists prepare the NACA reports.

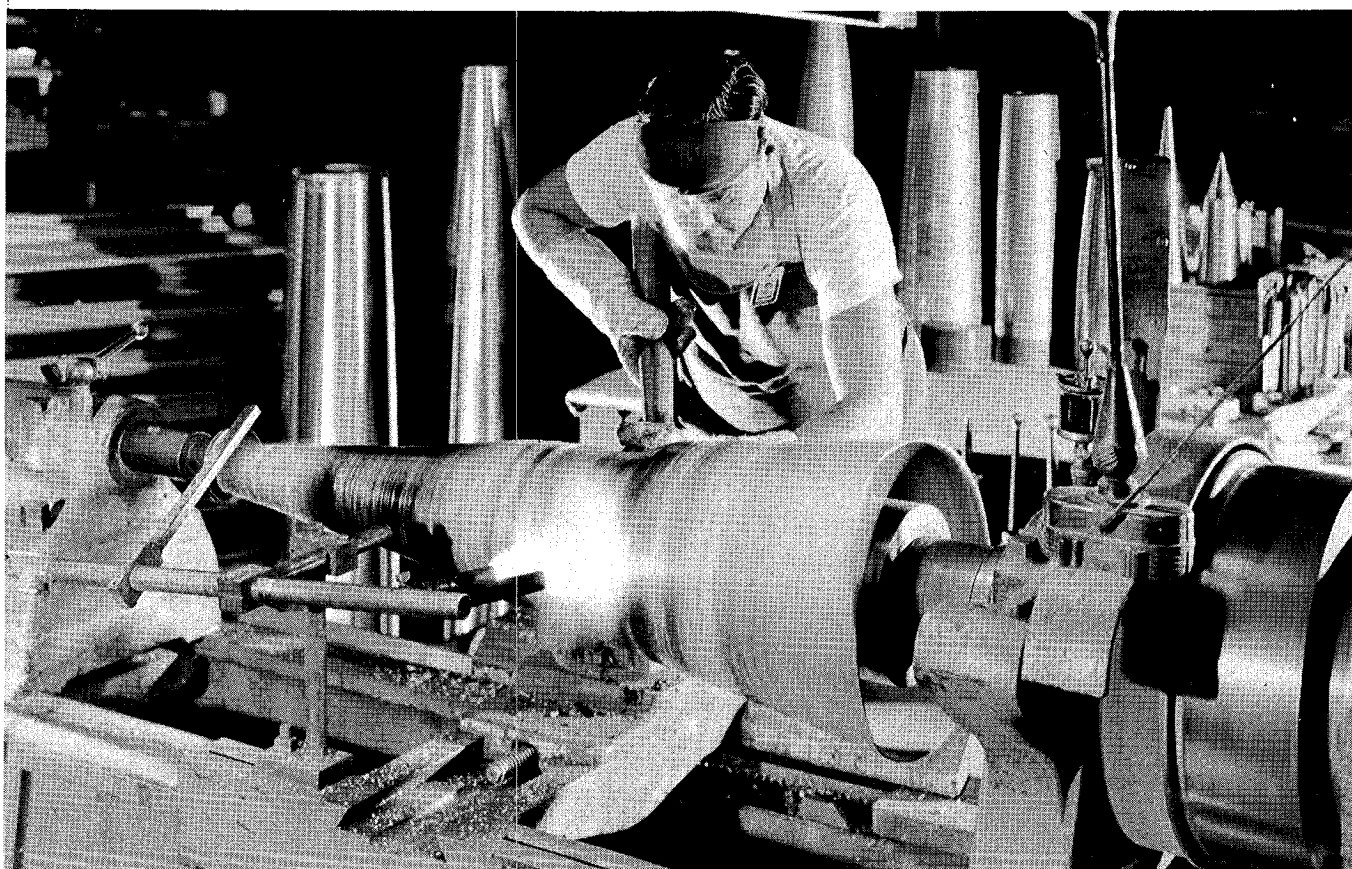
As the final step, NACA reports are printed in a shop that also handles blueprinting, photography, and technical illustration.



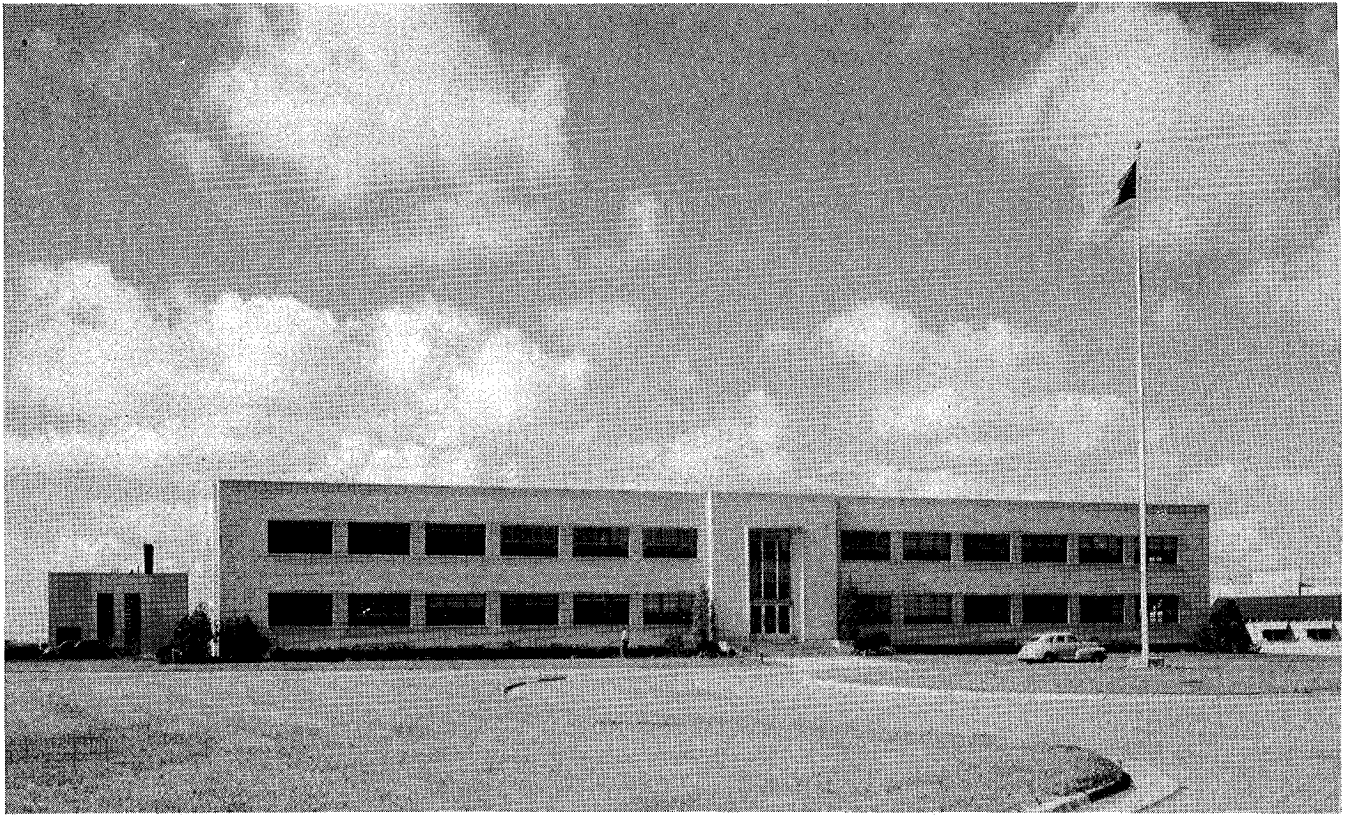
FEEDING PROBLEM INTO THE "MAGIC BRAIN"



PHOTOGRAPHER TRACKS ROCKET MODEL



AVIATION METALSMITH SHAPING MAGNESIUM SHELL OF ROCKET MODEL ON SPINNING LATHE



ADMINISTRATION BUILDINGS AT LEWIS (TOP) AND AMES LABORATORIES

PERSONNEL INFORMATION

Outlined below are some facts about becoming and being an NACA employee. They apply to each employee, whether he does research, conducts tests, makes the models used in the tests, runs the computing machines which analyze and make useful the "raw data," types reports, runs presses which print the reports, or does some other type of work.

All employees have the benefits of being under the U. S. Civil Service system. These benefits include hiring and pay on the basis of merit, an established promotion policy, protection against arbitrary dismissal, vacations and sick leave with pay, injury and death benefits, and a generous retirement plan.

OPENINGS AND APPOINTMENTS. The wide variety of specialties, the ever-changing nature of aeronautical research, and the shortage of certain kinds of qualified people help create openings in the NACA laboratories. The number of positions open and the types of available work vary from time to time, but there are usually vacancies in each research center at any given time.

Among the types of qualified persons frequently needed are engineers with degrees in such branches as aeronautical, mechanical and electrical engineering; physicists, metallurgists, chemists, electronics scien-

tists, and applied mathematicians; certain kinds of skilled craftsmen and shop workers such as model makers, instrument makers, metalsmiths and aircraft mechanics; draftsmen, photographers, and illustrators; clerks, typists, stenographers, messengers, and so on.

All employees are hired through the competitive system prescribed by the U. S. Civil Service Commission. Applications for employment may be sent direct to any laboratory.

PAY AND PROMOTIONS. All Civil Service positions are evaluated into grades or salary levels based on the difficulty of the work and the knowledge, skill, and experience required. NACA mechanics and craftsmen are paid at rates based upon prevailing wages in the local communities surrounding the NACA research centers.

Regular within-grade raises in pay are given every 12 months when performance is satisfactory (18 months for those in the upper salary brackets). Mechanics and craftsmen earn increases based on the efficiency of their performance.

Promotions to positions with more difficult duties for both scientific and supporting personnel may be quite rapid, depending upon the demonstrated ability and fitness of the employee to advance to higher-level duties.



EMPLOYEES EAT IN ATTRACTIVE CAFETERIAS AT THE LABORATORIES



INSTRUCTOR AND STUDENTS

TRAINING. The NACA takes positive steps to help its employees qualify for advancement. Not only do supervisors give employees on-the-job training, but a number of more formal training programs are in operation at the various research centers.

Training for research scientists and engineers includes the Aeronautical Research Intern and Junior Engineer program, laboratory lectures and seminars, evening graduate courses, graduate study leave, and use of NACA research data for master's and doctor's theses.

Formalized apprentice training is provided by the NACA in various skilled trades and crafts and engineering drafting. This program is approved by the Federal Committee on Apprenticeship and includes both on-the-job instruction and classroom work. The training continues four years for most skilled trades, five years for some. Satisfactory progress earns a promotion every year. Upon successful completion of the program, the apprentice is awarded a diploma issued jointly by the NACA and the Bureau of Apprenticeship of the U. S. Department of Labor, certifying that he is a full-fledged journeyman in his particular specialty.

In addition to these, various other training programs are organized at the research centers for supervisors, stenographers, typists, and others.

HOURS, HOLIDAYS, VACATION. The NACA has a regular 40-hour work week - eight hours a day, Monday through Friday. For some types of work there may be special shifts or night duty.

Eight regular holidays are observed, and occasionally others. When a holiday falls on Sunday, employees usually are excused from duty on Monday, the next day.

Government employees earn "annual leave," or time-off-with-pay for vacation and other purposes, on a graduated scale based on their length of federal and military service. During the first 3 years of service, 13 working days (2½ weeks) a year are earned. Those with 3 to 15 years of service earn 20 working days (4 weeks) a year, and those with over 15 years earn 26 days (5 weeks) a year. Work conditions permitting, an employee may use all of this leave for a single vacation-

with-pay, or he may use several days at a time, or even individual hours.

In addition to annual leave, 13 days of sick leave a year are earned by every employee regardless of his length of service. Unused sick leave is accumulated and remains to the employee's credit indefinitely. Over a period of years, this accumulation builds up a strong protection against the financial strain of prolonged illness.

COMPENSATION FOR INJURY. The Federal Employees' Compensation Act provides compensation, full medical care, certain funeral expenses, and other benefits for injury, occupational diseases, or death sustained in line of duty by employees. The provisions are too extensive to cover in this booklet.

RETIREMENT. Under the Civil Service Retirement Act, NACA employees obtain the financial benefits of a liberal retirement system. Each payday 6 percent of the employee's base pay is automatically deducted and then credited to his individual retirement account, where it immediately begins to earn interest at the rate of 3 percent. When he retires, the Government may contribute as much as or even more than the employee toward his annuity. The amount of the annuity is liberal, being determined by the employee's highest five consecutive years of salary, his length of service, and his



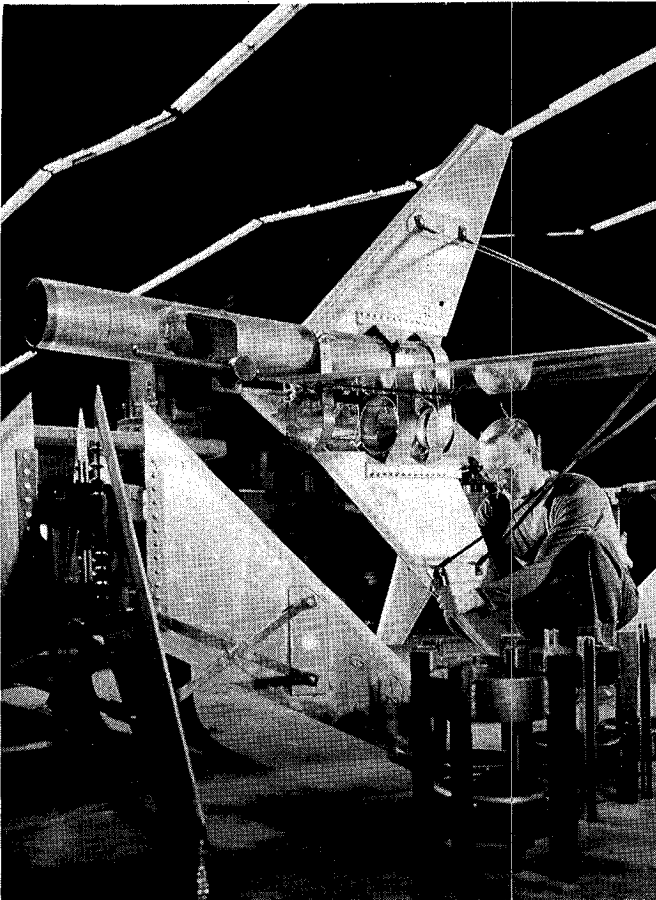
LANGLEY CAGERS PLAYING U. OF VIRGINIA

age at retirement. In case of death either before or after retirement, there are also benefits for his dependents or heirs.

If an employee's appointment is of a temporary or indefinite nature, he probably is covered by the Social Security law. In such cases, the deduction per payday is $1\frac{1}{2}$ percent on the first \$3,600 of annual salary. Like the Retirement Act deductions, Social Security contributions are added to by the Government to provide an income for the employee or his family in case his earnings are cut off by old age or death.

GROUP INSURANCE. Employees have the opportunity to obtain life insurance coverage at inexpensive group rates under the NACA Group Life Insurance Plan. Each employee who joins the Plan is insured for an amount based on his annual salary. No medical examination is necessary if the employee applies for this insurance within 31 days after entrance on duty.

CREDIT UNION. Employees may become members of an NACA Credit Union, established to encourage thrift through systematic savings and to help members in need of financial assistance. As members, employees can borrow limited amounts of cash and also can purchase shares which pay dividends usually higher than the interest on a bank savings account.



APPRENTICE-TRAINED SHEETMETAL WORKER



COMPUTER

PATENTS. The patent policy of the NACA is designed to stimulate inventiveness, and also to protect the employee's rights as well as those of the Government. Patents on inventions related to NACA's work programs will be secured without expense to the inventor. In the majority of cases, the employee retains the commercial rights, or all rights, of the patent, depending upon the nature of the invention. The only instance in which the Government assumes full title to an invention is when the idea is integrally connected with the specific work assignment of the employee.

SECURITY OF INFORMATION. The research performed by the NACA is important to the defense of the nation. For this reason much of the information produced is subject to security controls to prevent unauthorized disclosure which might endanger the security of our country. There are security laws and NACA regulations prescribed for the protection of both the individual and the Government.

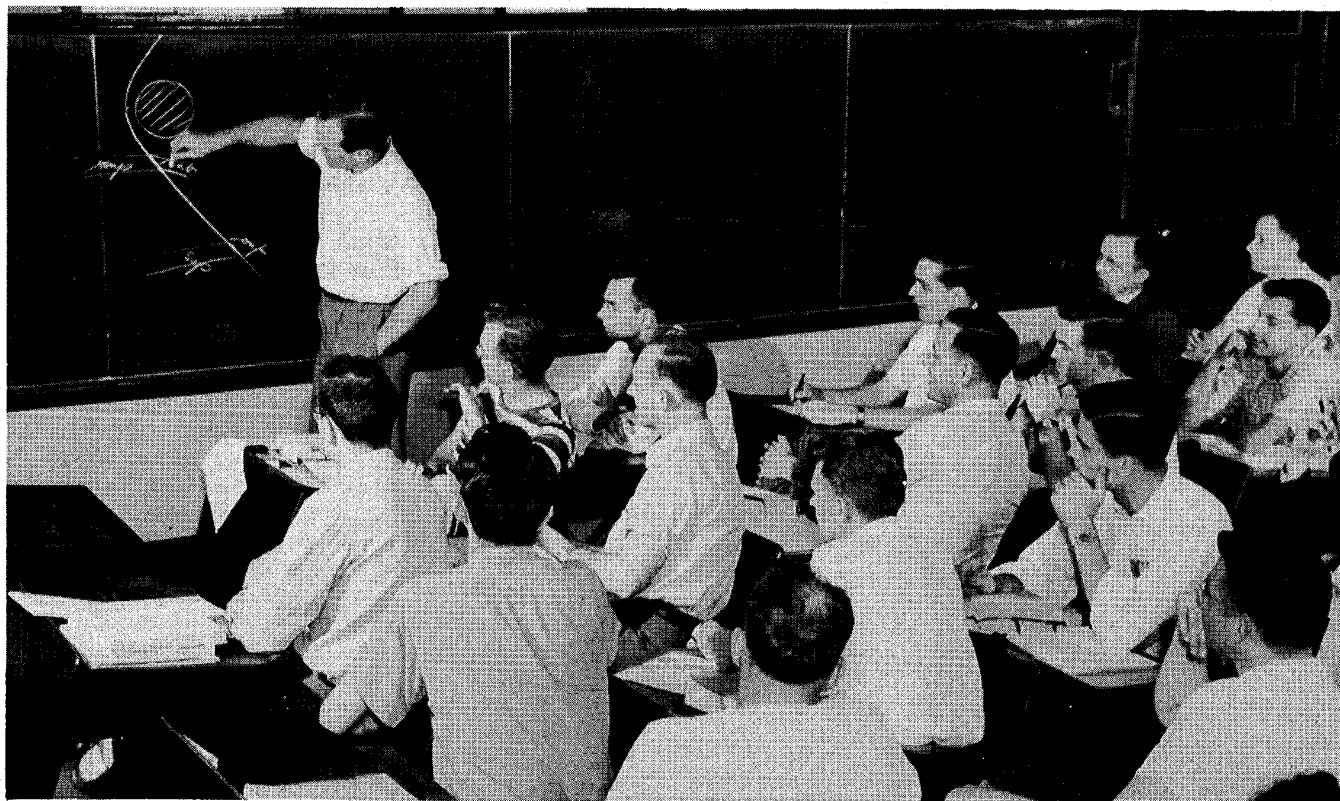
RECREATION. All three laboratories are situated in communities offering good living conditions and ample opportunities for sports and recreation. Langley and Ames are located in country areas near small towns and cities, and both enjoy the advantages of a mild climate. Lewis is in a suburban district near Lake Erie. All three laboratories have near at hand numerous cultural events and "big city" advantages: Lewis is only 12 miles from downtown Cleveland, Ames is close to Palo Alto and Stanford University and only 38 miles south of San Francisco, and Langley is not far from Norfolk and only a two-hour drive from Richmond.

Half a dozen sports readily available to workers at all three laboratories are boating, fishing, hunting, flying, golf, tennis and bowling. The Ames employees are not far from mountains, deserts, forests and seashore. Langley borders on Chesapeake Bay, a paradise for anglers and yachtsmen. Lake Erie is a summer-time attraction near Lewis. Interesting territory for motor trips is within range of all the laboratories.

Within the laboratories, encouragement and support are given to numerous clubs, teams, dances, meetings, and miscellaneous social events.



NACA HAS FINE REFERENCE LIBRARIES



EVENING CLASS IN AERODYNAMICS OF SUPERSONIC FLOW

YOUNG ENGINEERS AND SCIENTISTS

NACA develops them into Aeronautical Research Scientists

The accent is on youth in the NACA's constant search for well-trained, research-minded engineers and physical scientists. Nearly 70 percent of NACA's professional research workers join the staff shortly after graduating from college with a bachelor's degree. Young scientists develop research skill and knowledge rapidly, and soon make important additions to research knowledge.

Their college majors are highly varied. Of the nearly 1,900 research scientists now in NACA, about 80 percent have engineering degrees, the majority in aeronautical and mechanical, many in electrical and chemical, and some in civil, metallurgical, ceramic, etc. About 20 percent have physical science degrees, mostly in physics, mathematics, and chemistry, some in metallurgy, electronics, and other fields. These proportions result partly from the nature of NACA research work and partly from the relative availability of types of engineers and scientists.

Recent college graduates are hired as "aeronautical research interns." After six months of training and experience they are promoted to "aeronautical research scientist" positions. Those who have graduate degrees or professional experience are hired as scientists at higher starting salaries.

Along with his organized training, the new intern is almost immediately assigned to a specific research project, working with experienced scientists as a member of the team, often running tests and analyzing test data.

Meanwhile, the young scientist associates informally with professional colleagues who can give him sound advice regarding his career. At work, at meals, at classes, and at frequent professional meetings he mingles with scientists having national and international prestige. In addition, there are frequent lectures and seminar-type conferences across specialty lines, often including renowned authorities from universities and industry.

Furthermore, the NACA strongly encourages the young scientist to work toward an advanced degree. This is done in three ways. First, graduate courses in engineering, physics, electronics, advanced mathematics, etc., for university credit are offered in cooperation with nearby leading universities: University of Virginia, Stanford University, Case Institute of Technology. These are offered mostly in the evenings and are often taught by top NACA scientists. Second, the NACA has special Congressional authority to send selected scientists to universities for graduate study or research. Third, the NACA frequently allows scientists to use their own NACA research as the basis for a master's or doctor's thesis.

Members of the NACA scientific staff enjoy considerable freedom and latitude to do independent think-

ing and to develop their own ideas along the lines indicated by their research assignments. This freedom of ideas is accompanied to a considerable degree by freedom from repetitive or low-grade work. For each NACA professional research worker there are, on the average, three other NACA employees who aid directly or indirectly in his work. Large, well-equipped shops and staffs of highly skilled machinists, model makers, instrument technicians, draftsmen, and others, provide expert help with experimental equipment; trained computers and electronic machines carry the burden of mathematical detail; large specialized libraries and trained librarians facilitate searches through the technical literature; editors help prepare the research reports. The NACA has found that this three-to-one ratio provides the best support for highly-trained research professionals.

In addition, NACA scientists pursue their work in excellent, well-equipped laboratories. The NACA has numerous and varied wind tunnels, including transonic and hypersonic; test equipment for complete engines and separate components; laboratories for fuels, combustion, materials, structures, hydrodynamics, etc. Much of the research equipment is unique. The NACA and its research staff are respected - and its facilities are considered unparalleled - the world over.

The record shows that the NACA offers stable as well as attractive employment for scientists, with excellent opportunities for advancement. Scientists are promoted as they demonstrate their capacity to do more difficult work. And the opportunity to do more difficult work is always present in the NACA research program, as challenging unsolved problems arise on the expanding frontiers of aeronautical science.

It is not uncommon for a man who has been with NACA only 10 or 12 years to move up to head or assistant head of a major research group or experimental facility. Also, the NACA is far ahead of most organizations in advancing young scientists to non-supervisory research positions at the highest levels, where individual scientific knowledge and ability are recognized without imposing heavy loads of administrative work.

In this stimulating professional atmosphere and helpful environment, the young scientist can develop rapidly and gain considerable prestige early in his career. His name may appear within a year as author or co-author of reports or technical notes distributed nationally and internationally by NACA. He may be one of the NACA scientists invited to deliver technical papers on their specialties at meetings of the Institute of the Aeronautical Sciences and other professional societies. These NACA reports and professional papers, bearing the imprint of authority in the aviation world, soon start to establish him as an expert in his field.

COLLEGE MAJORS APPROPRIATE FOR NACA RESEARCH SPECIALTIES AT THE "INTERN" OR BACHELOR'S-DEGREE LEVEL

Locations of Work	NACA Research Specialties	Physics	Eng'g Physics	Mech. Eng'g	Aero. Eng'g	Electrical E.	Electronics	Civil Eng'g	Chem. Eng'g	Chemistry	Naval Arch.	Metallurgy	Metal. Eng'g	Ceramic Eng'g
Langley Ames Lewis Edwards	Aerodynamics	✓	✓	✓	✓	✓								
Langley Lewis Edwards	Propulsion	✓	✓	✓	✓	✓			✓					
Langley Edwards	Aircraft Structures	✓	✓	✓	✓			✓						
Lewis	Propulsion-Systems Structures	✓	✓	✓	✓									
Langley Ames Lewis Edwards	Instrumentation	✓	✓	✓		✓	✓							
Lewis	Combustion			✓	✓				✓	✓				
Langley	Hydrodynamics			✓	✓						✓			
Lewis	Propulsion-Systems Materials											✓	✓	✓
Langley Ames Lewis Edwards	Aeronautical Theory	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
(if courses included certain higher mathematics)														

Shown above are the NACA research specialties available for the recent bachelor's-degree graduate. There are many more specialties and a wider range of acceptable college majors for those who have re-

search experience or a graduate degree.

There are also nonresearch engineering specialties, particularly for those with mechanical, electrical, or civil degrees.

NACA Langley Aeronautical Laboratory, Langley Field, Virginia
NACA Ames Aeronautical Laboratory, Moffett Field, California
NACA Lewis Flight Propulsion Laboratory, Cleveland, Ohio
NACA Edwards High-Speed Flight Research Station, Edwards, California